National Aeronautics and
Space Administration

Educational Product	
Educators	Grades K–12

LS-2001-08-002-HQ

Solar System Lithograph Set

for Space Science

This set contains the following lithographs:

- Our Solar System
- Our Star—The Sun
- Mercury
- Venus
- Earth
- Moon
- Mars
- Asteroids
- Jupiter
- Moons of Jupiter
- Saturn
- Uranus
- Neptune
- Pluto and Charon
- Comets

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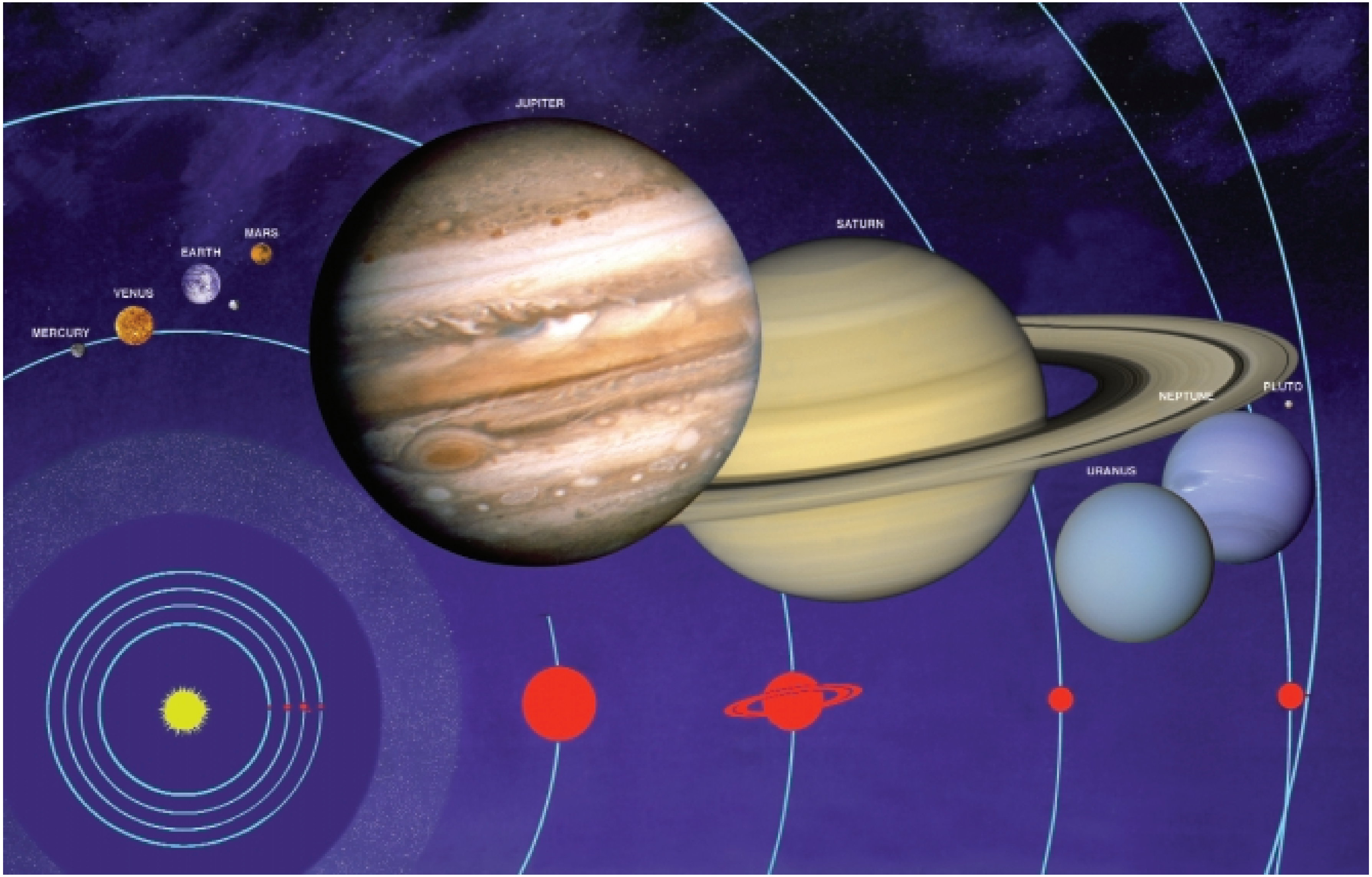
Our Solar System



Our Solar System

From our small world we have gazed upon the cosmic ocean for thousands of years. Ancient astronomers observed points of light that appeared to move among the stars. They called these objects planets, meaning wanderers, and named them after Roman deities—Jupiter, king of the gods; Mars, the god of war; Mercury, messenger of the gods; Venus, the goddess of love and beauty; and Saturn, father of Jupiter and god of agriculture. The stargazers also observed comets with sparkling tails, and meteors or shooting stars apparently falling from the sky.

Since the invention of the telescope, three more planets have been discovered in our solar system: Uranus (1781), Neptune (1846), and Pluto (1930). In addition, there are thousands of small bodies such as asteroids and comets. Most of the asteroids orbit in a region between the orbits of Mars and Jupiter, while the home of comets lies far beyond the orbit of Pluto, in the Oort Cloud.

The four planets closest to the Sun—Mercury, Venus, Earth, and Mars—are called the *terrestrial planets* because they have solid rocky surfaces. The four large planets beyond the orbit of Mars—Jupiter, Saturn, Uranus, and Neptune—are called gas giants. Tiny, distant Pluto has a solid but icier surface than the terrestrial planets.

Nearly all of the planets—and some of the moons—have atmospheres. Earth's atmosphere is primarily nitrogen and oxygen. Venus has a thick atmosphere of carbon dioxide, with traces of poisonous gases such as sulfur dioxide. Mars' carbon dioxide atmosphere is extremely thin. Jupiter, Saturn, Uranus, and Neptune are primarily hydrogen and helium. When Pluto is near the Sun, it has a thin atmosphere, but when Pluto travels to the outer regions of its orbit, the atmosphere freezes and "collapses" to the planet's surface. In this regard, Pluto acts like a comet.

There are at least 91 natural satellites (also called moons) around the various planets in our solar system, ranging from bodies larger than our own Moon down to small pieces of debris. Many of these were discovered by planetary spacecraft. Some of these have atmospheres (Saturn's Titan); some even have magnetic fields (Jupiter's Ganymede). Jupiter's moon Io is the most volcanically active body in the solar system. An ocean may lie beneath the frozen crust of Jupiter's moon Europa, while images of Jupiter's moon Ganymede show historical motion of icy crustal plates. Some planetary moons, such as Phoebe at Saturn, may be asteroids that were captured by a planet's gravity.

From 1610 to 1977, Saturn was thought to be the only planet with rings. We now know that Jupiter, Uranus, and Neptune also have ring systems, although Saturn's is by far the largest. Particles in these ring systems range in size from dust to boulders to house-sized, and they may be rocky and/or icy.

Most of the planets also have magnetic fields, which extend into space and form a "magnetosphere" around each planet. These magnetospheres rotate with the planet, sweeping charged particles with them. The Sun has a magnetic field, the heliosphere, which envelops our entire solar system.

Ancient astronomers believed that the Earth was the center of the universe and that the Sun and all the other stars revolved around the Earth. Copernicus proved that Earth and the other planets in our solar system orbit our Sun. Little by little, we are charting the universe, and obvious questions arise: Are there other planets around other stars? Are there other planets where life might exist? Only recently have astronomers had the tools to indirectly detect large planets around other stars in nearby galaxies. Direct detection and characterization of such planets awaits the development of yet more powerful observing tools and techniques.

The illustration on the reverse side is an artistic representation of the planets' sizes and distances.

Activities

How big is our solar system? To give you a rough idea, consider that it took the *Voyager 2* spacecraft, traveling in a sweeping arc at an average of 65,000 kilometers per hour, 12 years to reach Neptune! How fast is that in meters per second? In feet per second? If you could travel that fast, how long would it take you to reach the next town? To get to the Moon?

Can you build a scale model of the solar system? If you use Earth's diameter as a unit of measure (Earth diameter = 1), figure out how big the other planets are compared to Earth. Hint: divide each planet's diameter by Earth's diameter. What objects might you use to depict the sizes of the Sun and planets? How far away would the planets be from each other? Map out a scale model of the solar system in your town.

	Actual Diameter (km)	Mean Distance from sun (km)	Number of Moons
Sun	1,391,900	0	–
Mercury	4,878	57,910,000	0
Venus	12,104	108,200,0000	0
Earth	12,756	149,600,0001	1
Moon	3,476		–
Mars	6,794	227,940,000	2
Jupiter	142,984	778,330,000	28
Saturn	120,536	1,429,400,000	30
Uranus	51,118	2,870,990,000	21
Neptune	49,528	4,504,300,000	8
Pluto	2,300	5,913,520,000	1

References
1) Views of the Solar System—Solar System: *http://www.solarviews.com*
2) Planetary Photo Journal: *http://photojournal.jpl.nasa.gov*
3) Stardate: *http://stardate.org*

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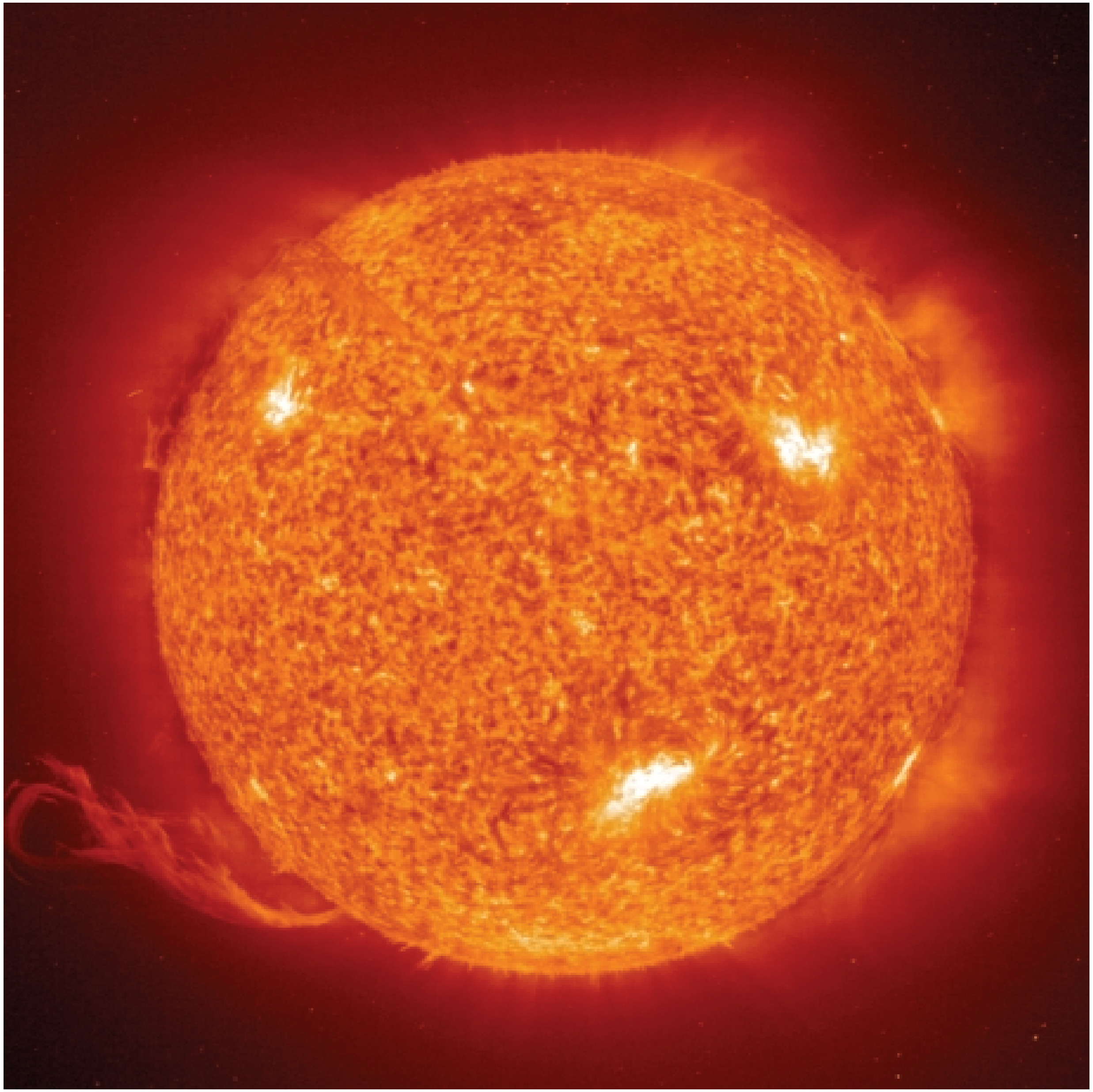
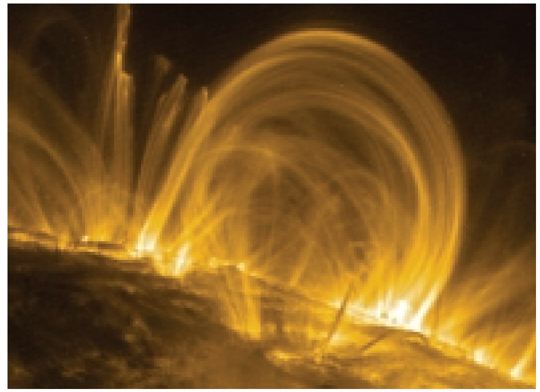
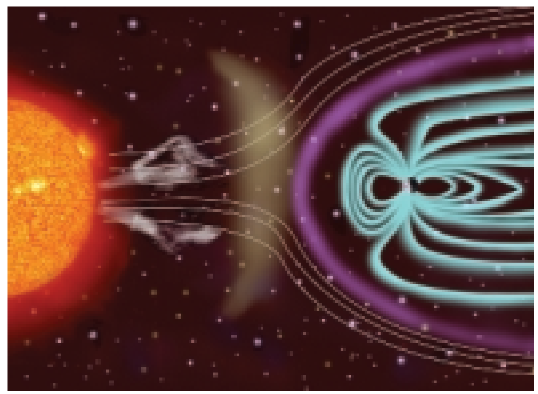
Sun ☉







Sun ⊙

Our **SUN** has inspired mythology in almost all cultures, including ancient Egyptians, Aztecs, Native Americans, and Chinese. We now know that the Sun is a huge, bright sphere of mostly ionized gas, about 4.5 billion years old, and is the closest star to Earth at a distance of about 150 million km. The next closest star—Proxima Centauri—is nearly 268,000 times farther away. There are millions of similar stars in the Milky Way Galaxy (and billions of galaxies in the universe). Our Sun supports life on Earth. It powers photosynthesis in green plants and is ultimately the source of all food and fossil fuel. The connection and interaction between the Sun and the Earth drive the seasons, currents in the ocean, weather, and climate.

The Sun is some 333,400 times more massive than Earth and contains 99.86 percent of the mass of the entire solar system. It is held together by gravitational attraction, producing immense pressure and temperature at its core (more than a billion times that of the atmosphere on Earth, with a density about 160 times that of water).

At the core, the temperature is 16 million degrees kelvin (K), which is sufficient to sustain thermonuclear fusion reactions. The released energy prevents the collapse of the Sun and keeps it in gaseous form. The total energy radiated is 383 billion trillion kilowatts, which is equivalent to the energy generated by 100 billion tons of TNT exploding each second.

In addition to the energy-producing solar core, the interior has two distinct regions: a radiative zone and a convective zone. From the edge of the core outward, first through the radiative zone and then through the convective zone, the temperature decreases from 8 million to 7,000 K. It takes a few hundred thousand years for photons to escape from the dense core and reach the surface.

The Sun's "surface," known as the photosphere, is just the visible 500-km-thick layer from which most of the Sun's radiation and light finally escape, and it is the place where sunspots are found. Above the photosphere lies the chromosphere ("sphere of color") that may be seen briefly during total solar eclipses as a reddish rim, caused by hot hydrogen atoms, around the Sun. Temperature steadily increases with altitude up to 50,000 K, while density drops to 100,000 times less than in the photosphere. Above the chromosphere lies the corona ("crown"), extending outward from the Sun in the form of the "solar wind" to the edge of the solar system. The corona is extremely hot—millions of degrees kelvin. Since it is physically impossible to transfer thermal energy from the cooler surface of the Sun to the much hotter corona, the source of coronal heating has been a scientific mystery for more than 60 years. Scientists believe that energy transfer has to be in the form of waves or magnetic energy. Likely solutions have emerged from recent *SOHO* and *TRACE* satellite observations, which found evidence for the upward transfer of magnetic energy from the Sun's surface toward the corona above. Researchers in NASA's Sun-Earth Connection Space Science theme study these myserious phenomena.

Fast Facts

Spectral Type of Star	G2 V
Age	4.5 billion years
Mean Distance to Earth	150 million km
Rotation Period (at equator)	26.8 days
Rotation Period (at poles)	36 days
Diameter	1.4 million km
Mass	1.99×10^{30} kilograms
Composition (number of atoms)	92.1% Hydrogen, 7.8% Helium
Temperature (photosphere)	5,780 K
Energy Output (luminosity)	3.83×10^{33} ergs/sec

Significant Dates

585 BC	First solar eclipse successfully predicted.
1610	Galileo observes sunspots with his telescope.
1650–1715	Maunder Sunspot Minimum discovered.
1854	First connection made between solar activity and geomagnetic activity.
1868	Helium lines first observed in solar spectrum.
1942	First radio emission from Sun observed.
1946	Corona temperature discovered to be 1,000,000 K.
1959	First direct observations of solar wind made by *Mariner 2*.
1973–74	*Skylab* observed Sun, discovered coronal holes.
1982	First observations of neutrons from a solar flare by *Solar Maximum Mission (SMM)*.
1991	Japan's *Yohkoh* satellite studies x rays and gamma rays.
1994–95 & 2000–01	ESA/NASA *Ulysses* mission studies polar regions of Sun.
1995	ESA/NASA's *Solar and Heliospheric Observatory (SOHO)* studies the solar interior, atmosphere, and wind.
1998	NASA's *Transition Region and Coronal Explorer* satellite observes the photosphere, transition region, and corona.

About the Images

(Left) Activity in the Sun seen in extreme ultraviolet by the *SOHO* satellite. Large erupting prominences (such as seen in the lower left of the image), when aimed in the direction of the Earth, can cause major disruptions in the near-Earth environment, affecting communications, navigation systems, and even power grids. The effects of these solar storms can be seen as auroral displays near the Earth's poles, the Northern and Southern Lights (*SOHO/EIT*).
(Right, top) The surface of the Sun with several sunspots. A sunspot is a dark part of the Sun's surface that is cooler than the surrounding area. A sunspot also temporarily has a concentrated magnetic field. This magnetic force inhibits the convective motion that ordinarily brings hot matter up from the interior of the sun. Sunspots are about 4,000 K, compared to the temperature of 5,700 K in the rest of the photosphere (*SOHO/MDI*).
(Right, center) Clusters of majestic hot coronal loops span 30 or more times the diameter of planet Earth (*TRACE/LMSAL*).
(Right, bottom) Artist's conception of high-speed gas from the Sun, the solar wind, traveling at speeds ranging from 250 to 1,000 km per second as it sweeps past and distorts a planet's magnetic field. NASA's *Genesis* mission will bring samples of the solar wind back to Earth (*SOHO/Extreme Ultraviolet Imaging Consortium*).

References
1) Sun-Earth Connection Education Forum: *http://sunearth.gsfc.nasa.gov*
2) Mission to Geospace: *http://www-istp.gsfc.nasa.gov/istp/outreach*
3) Yohkoh Public Outreach Project: *http://solar.physics.montana.edu/YPOP*
4) *Ulysses* Mission: *http://ulysses.jpl.nasa.gov*
5) *Solar and Heliospheric Observatory* (SOHO): *http://sohowww.nascom.nasa.gov*
6) *Transition Region and Coronal Explorer* (TRACE): *http://vestige.lmsal.com/TRACE*
7) *Genesis* Mission: *http://genesis.jpl.nasa.gov*

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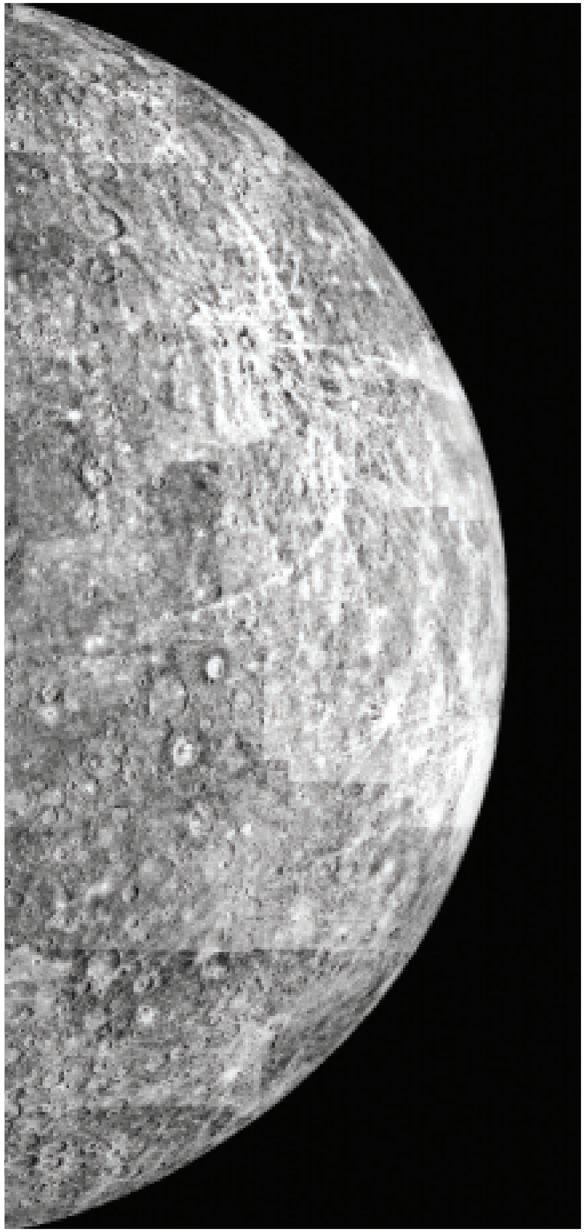

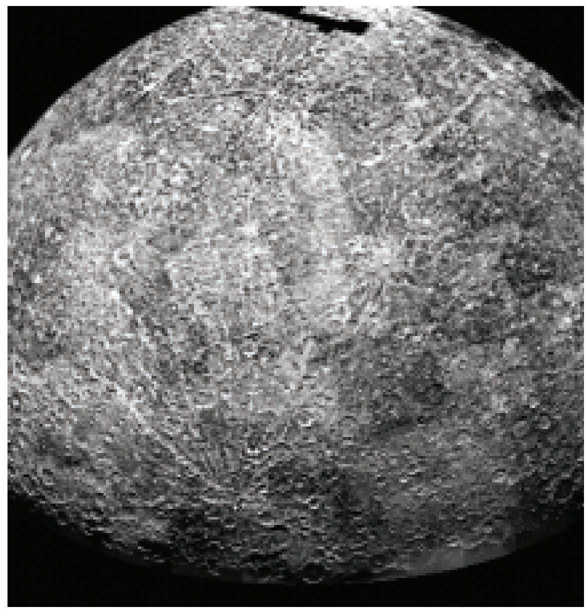

Mercury ☿

The small and rocky planet **MERCURY** is the closest planet to the Sun; it speeds around the Sun in a wildly elliptical (non-circular) orbit that takes it as close as 47 million km and as far as 70 million km from the Sun. Mercury completes a trip around the Sun every 88 days, speeding through space at nearly 50 km per second, faster than any other planet. Because it is so close to the Sun, temperatures on its surface can reach a scorching 467 degrees Celsius. But because the planet has hardly any atmosphere to keep it warm, nighttime temperatures can drop to a frigid -183 degrees Celsius.

Because Mercury is so close to the Sun, it is hard to see from Earth except during twilight. Until 1965, scientists thought that the same side of Mercury always faced the Sun. Then, astronomers discovered that Mercury completes three rotations for every two orbits around the Sun. If you wanted to stay up for a Mercury day, you'd have to stay up for 176 Earth days!

Like our Moon, Mercury has almost no atmosphere. What little atmosphere exists is made up of atoms blasted off its surface by the solar wind and has less than a million-billionths the pressure of Earth's atmosphere at sea level. It is composed chiefly of oxygen, sodium, and helium. Because of Mercury's extreme surface temperature, these atoms quickly escape into space and are constantly replenished. With no atmosphere to protect the surface, there has been no erosion from wind or water, and meteorites do not burn up due to friction as they do in other planetary atmospheres.

Mercury's surface very much resembles Earth's Moon, scarred by thousands of impact craters resulting from collisions with meteors. While there are areas of smooth terrain, there are also cliffs, some soaring up to a mile high, formed by ancient impacts.

The Caloris Basin, one of the largest features on Mercury, is about 1,300 km in diameter. It was the result of an asteroid impact on the planet's surface early in the solar system's history, the probable cause of the strange surfaces on the opposite side of the planet. Over the next half-billion years, Mercury actually shrank in radius from 2 to 4 km as the planet cooled from its formation. The outer crust, called the lithosphere, was compressed and grew strong enough to prevent the planet's magma from reaching the surface, effectively ending the planet's period of geologic activity. Evidence of Mercury's active past is seen in the smooth plains in the Caloris basin.

Mercury is the second smallest planet in the solar system, larger only than Pluto, the most distant planet in our solar system. If Earth were the size of a baseball, Mercury would be the size of a golf ball. Viewed from Mercury, the Sun would look almost three times as large as it does from Earth. Mercury is the second densest body in the solar system after Earth, with an interior made of a large iron core with a radius of 1,800 to 1,900 km, nearly 75 percent of the planet's diameter and nearly the size of Earth's Moon. Mercury's outer shell, comparable to Earth's outer shell (called the mantle) is only 500 to 600 km thick.

Only one spacecraft has ever visited Mercury: *Mariner 10* in 1974–75. *Mariner 10*'s discovery that Mercury has a very weak magnetic field, similar to but weaker than Earth's, was a major surprise. In 1991, astronomers using radar observations showed that Mercury may have water ice at its north and south poles. The ice exists inside deep craters. The floors of these craters remain in perpetual shadow, so the Sun cannot melt the ice.

NASA is planning a new mission to Mercury called *Mercury Surface, Space Environment, Geochemistry, and Ranging (MESSENGER)*, which will orbit Mercury toward the end of this decade. *MESSENGER* will investigate key science questions using a set of miniaturized instruments: Why is Mercury so dense? What is the geologic history of Mercury? What is the structure of Mercury's core? What is the nature of Mercury's magnetic field? What are the unusual materials at Mercury's poles? What volatiles are important on Mercury?

Fast Facts

Namesake	Messenger of the Roman Gods
Mean Distance from Sun	57.9 million km
Orbital Period	88 days
Orbital Eccentricity	0.206
Orbital Inclination to Ecliptic	7°
Inclination of Equator to Orbit	0°
Rotational Period	58 d 39 m
Diameter	4,879 km
Mass	0.06 of Earth's
Density	5.43 g/cm^3
Gravity	0.38 of Earth's
Atmosphere (primary components)	Oxygen, Sodium, Helium
Temperature Range	-183 °C (night) to +467 °C (day)
Number of Moons	0
Number of Rings	0

Significant Dates

1610 Italian astronomer Galileo Galilei made first telescopic observation of Mercury.

1631 French astronomer Pierre Gassendi made first telescopic observations of the transit of Mercury across the face of the Sun.

1639 Italian astronomer Giovanni Zupus discovered that Mercury has phases, which is evidence that the planet circles the Sun.

1641 German astronomer Johann Franz Encke made the first mass determination using the gravity effect on the comet Encke.

1889 Italian astronomer Giovanni Schiaparelli produced the first map of Mercury's surface features.

1965 American radio astronomers Gordon Pettengill and Rolf Dyce measured Mercury's rotation period to be about 59 days.

1968 *Surveyor 7* took the first spacecraft picture of Mercury from the lunar surface.

1974 *Mariner 10* made the first flyby within 705 km of Mercury.

1975 *Mariner 10* made its third and final flyby of Mercury at 327 km.

About the Images

(Left and center) Mercury, much like the Moon, presents two totally different faces, one battered (and thus older) and one smoother (and thus younger) *(Mariner 10)*.

(Right, top) Caloris Basin was undoubtedly produced from a tremendous impact. A circular mountain range surrounding the wrinkled terrain at left defines the basin's main rim *(Mariner 10)*.

(Right, bottom) Photomosaic of Mercury's southern hemisphere *(Mariner 10)*.

References

1) *MESSENGER* Mission: *http://sd-www.jhuapl.edu/MESSENGER*

2) Views of the Solar System—Mercury: *http://www.solarviews.com/eng/mercury.htm*

3) NASA Planetary Photojournal: *http://photojournal.jpl.nasa.gov*

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National Aeronautics and
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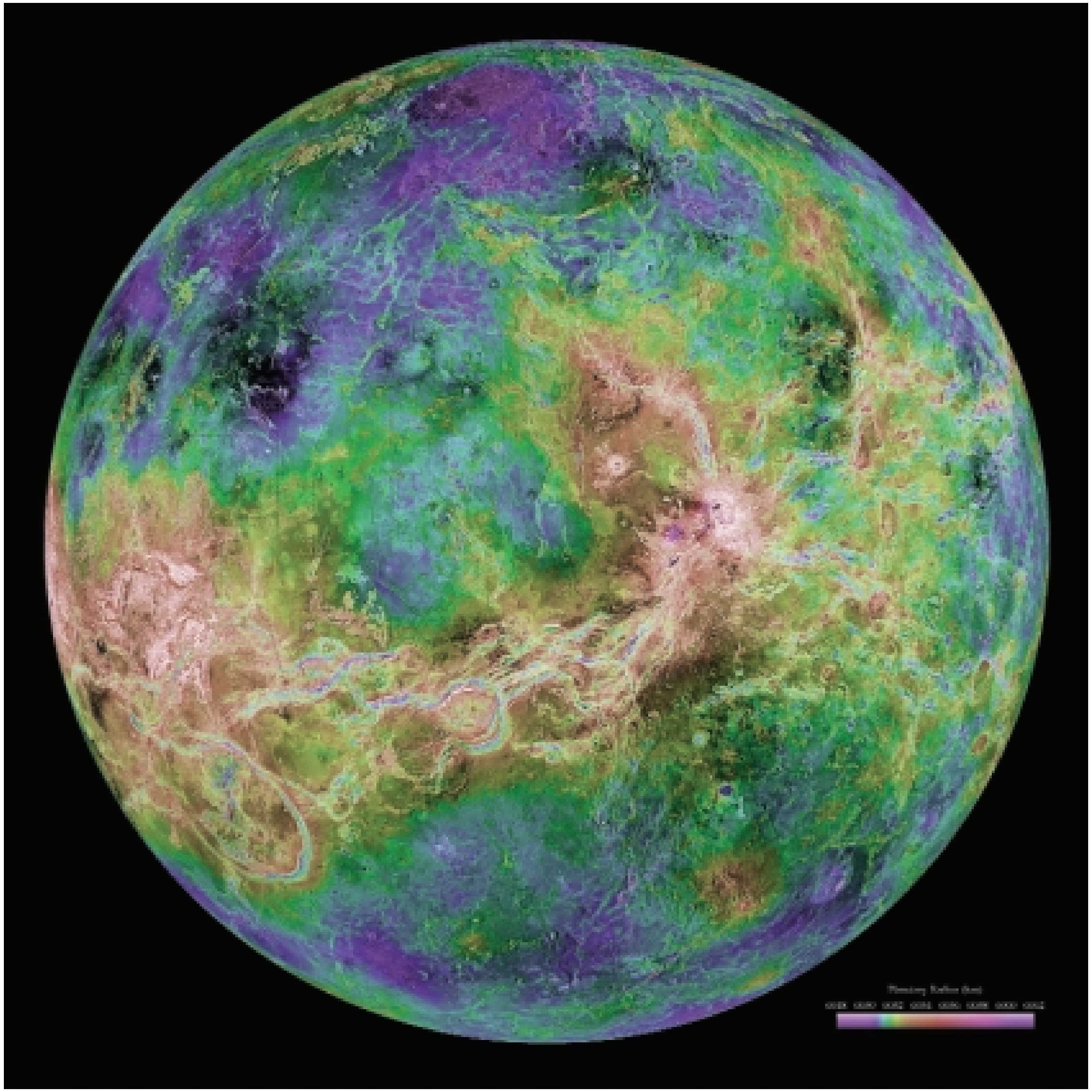
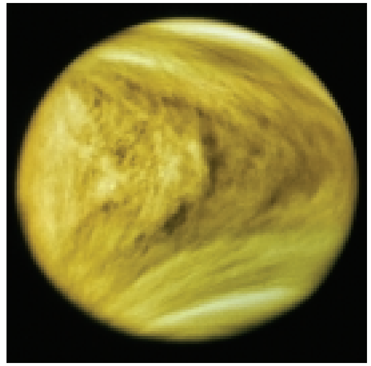
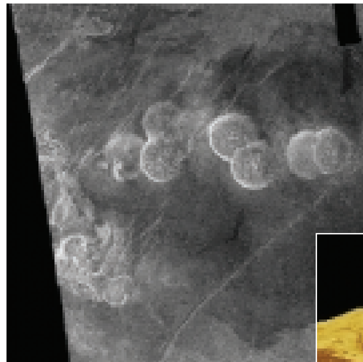
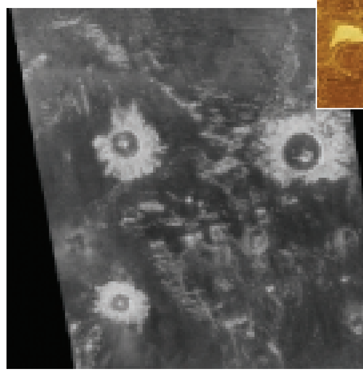
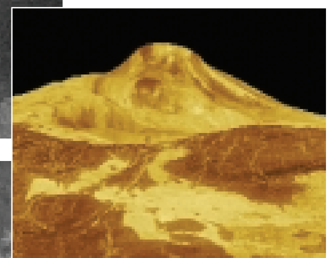
Venus ♀











National Aeronautics and Space Administration

Venus ♀

At first glance, if Earth had a twin, it would be **VENUS**. The two planets are similar in size, mass, composition, and distance from the Sun. But there the similarities end. Venus has no ocean. Venus is covered by thick, rapidly spinning clouds that trap surface heat, creating a scorched greenhouse-like world with temperatures hot enough to melt lead and pressure so intense that standing on Venus would feel like the pressure felt 900 meters deep in Earth's oceans. These clouds reflect sunlight in addition to trapping heat. Because Venus reflects so much sunlight, it is usually the brightest planet in the sky.

The atmosphere consists mainly of carbon dioxide (the same gas that produces fizzy sodas), droplets of sulfuric acid, and virtually no water vapor—not a great place for people or plants! In addition, the thick atmosphere allows the Sun's heat in but does not allow it to escape, resulting in surface temperatures over 450 °C, hotter than the surface of the planet Mercury, which is closest to the Sun. The high density of the atmosphere results in a surface pressure 90 times that of Earth, which is why probes that have landed on Venus have only survived several hours before being crushed by the incredible pressure. In the upper layers, the clouds move faster than hurricane-force winds on Earth.

Venus sluggishly rotates on its axis once every 243 Earth days, while it orbits the Sun every 225 days—its day is longer than its year! Besides that, Venus rotates retrograde, or "backwards," spinning in the opposite direction of its orbit around the Sun. From its surface, the Sun would seem to rise in the west and set in the east.

Earth and Venus are similar in density and chemical compositions, and both have relatively young surfaces, with Venus appearing to have been completely resurfaced 300 to 500 million years ago.

The surface of Venus is covered by about 20 percent lowland plains, 70 percent rolling uplands, and 10 percent highlands. Volcanism, impacts, and deformation of the crust have shaped the surface. No direct evidence of currently active volcanoes has been found, although large variations of sulfur dioxide in the atmosphere lead some scientists to suspect that volcanoes may be active.

Although no rainfall, oceans, or strong winds exist to erode surface features, some weathering and erosion does occur. The surface is brushed by gentle winds, no stronger than a few kilometers per hour, enough to move grains of sand, and radar images of the surface show wind streaks and sand dunes. In addition, the corrosive atmosphere probably chemically alters rocks. Impact cratering is also affected by the dense atmosphere: craters smaller than 1.5 to 2 km across do not exist on Venus, largely because small meteors burn up in Venus' dense atmosphere before they can reach the surface.

More than 1,000 volcanoes or volcanic centers larger than 20 km in diameter dot the surface of Venus. There may be close to a million volcanic centers that are over 1 km in diameter. Much of the surface is covered by vast lava flows. In the north, an elevated region named Ishtar Terra is a lava-filled basin larger than the continental United States. Near the equator, the Aphrodite Terra highlands, more than half the size of Africa, extend for almost 10,000 km. Volcanic flows have also produced long, sinuous channels extending for hundreds of kilometers.

With few exceptions, features on Venus are named for accomplished women from all of Earth's cultures.

Venus's interior is probably very similar to that of Earth, containing an iron core about 3,000 km in radius and a molten rocky mantle covering the majority of the planet. Recent results from the *Magellan* spacecraft suggest that Venus' crust is stronger and thicker than had previously been thought.

Venus has no satellites and no intrinsic magnetic field, but the solar wind rushing by Venus creates a pseudo-field around the planet.

Fast Facts

Namesake	Roman Goddess of Love and Beauty
Mean Distance from Sun	108.2 million km
Orbital Period	224.695 days
Orbital Eccentricity	0.007
Orbital Inclination to Ecliptic	3.4°
Inclination of Equator to Orbit	177.3°
Rotational Period	243 d (retrograde)
Diameter	12,100 km
Mass	0.82 of Earth's
Density	5.24 g/cm^3
Gravity	0.91 of Earth's
Atmosphere (primary component)	Carbon Dioxide
Mean Temperature at Solid Surface	457 °C
Number of Moons	0
Number of Rings	0

Significant Dates

1962	*Mariner 2* (U.S.) flew by Venus; verified high temperatures.
1970	*Venera 7* (U.S.S.R.) soft-landed on Venus.
1972	*Venera 8* (U.S.S.R.) landed on Venus; transmitted nearly an hour of data.
1974	*Mariner 10* (U.S.), bound for Mercury, flew by Venus; tracked global atmospheric circulation with visible and ultraviolet imagery.
1975	*Venera 9* (U.S.S.R.) sent the first surface pictures of Venus via its orbiter.
1978	*Pioneer Venus Orbiter* (U.S.) radar mapped Venus; *Pioneer Venus Multiprobe* (U.S.) dropped four probes through Venusian clouds.
1983	*Venera 15* and *16* (U.S.S.R.) provided high-resolution mapping radar and atmospheric analyses.
1984	*Vega 1* and *2* (U.S.S.R.) dropped off landers and balloon probes at Venus while en route to Halley's comet.
1989	*Magellan* (U.S.) was launched toward Venus.
1990–94	*Magellan* (U.S.) mapped 98 percent of the surface of Venus using radar.

About the Images

(Left) Only radar can penetrate Venus's thick clouds to reveal its topography (blues are low areas; tans are high areas). Aphrodite Terra, a bright highland roughly the size of Africa, winds across Venus's southern hemisphere (false-color image data from *Magellan*, *Arecibo Observatory*, *Pioneer Venus*, and *Venera*).
(Right, top) Venus's thick clouds of carbon dioxide produce a "runaway greenhouse effect." The Y-shaped cloud patterns indicate wind speeds up to 500 km per hour in the upper layers of the atmosphere (*Pioneer Venus* near-ultraviolet image).
(Right, center) This cluster of large craters in an area the size of Michigan range in diameter from 50 to 37 km (*Magellan*).
(Right, bottom) Seven steep-sided and flat-topped domes of lava have oozed onto the plains east of Alpha Regio. They average 25 km in diameter with maximum heights of 750 meters (*Magellan*).
(Far right) Bright areas of ancient lava blanket the flanks of the 6-km-high volcano Maat Mons. The vertical scale in this image has been exaggerated 23 times to enhance small features and aid analysis of the area. The color is simulated based on data by the Soviet *Venera 13* and *14* spacecraft (*Magellan*).

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3) NASA Planetary Photojournal: *http://photojournal.jpl.nasa.gov*
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National Aeronautics and
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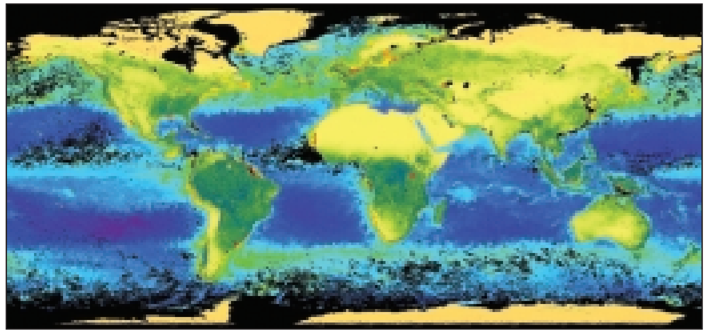
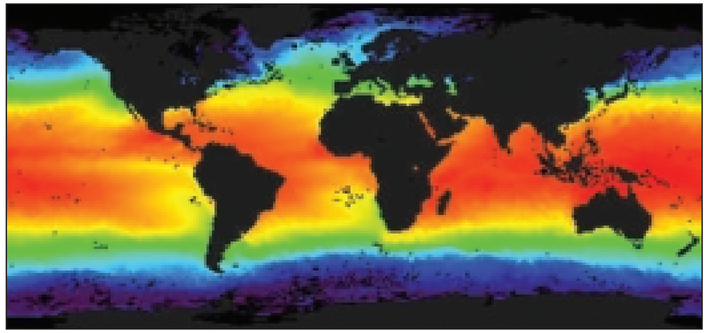
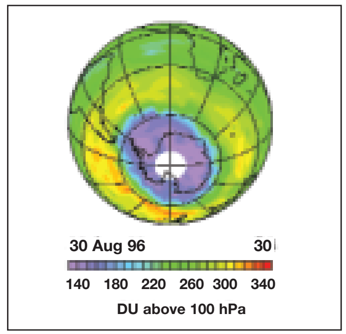
Earth







EARTH, our home planet, is the only planet in our solar system known to harbor life—life that is incredibly diverse. All of the things we need to survive are provided under a thin layer of atmosphere that separates us from the uninhabitable void of space. Earth is made up of complex, interactive systems that are often unpredictable. Air, water, land, and life—including humans—combine forces to create a constantly changing world that we are striving to understand.

Viewing Earth from the unique perspective of space provides the opportunity to see Earth as a whole. Scientists around the world have discovered many things about our planet by working together and sharing their findings.

Some facts are well known. For instance, Earth is the third planet from the Sun and the fifth largest in the solar system. Earth's diameter is just a few hundred kilometers larger than that of Venus. The four seasons are a result of Earth's axis of rotation being tilted more than 23 degrees.

Oceans at least 4 km deep cover nearly 70 percent of Earth's surface. Fresh water exists in the liquid phase only within a narrow temperature span (0 degrees to 100 degrees Celsius). This temperature span is especially narrow when contrasted with the full range of temperatures found within the solar system. The presence and distribution of water vapor in the atmosphere is responsible for much of Earth's weather.

Near the surface, an ocean of air that consists of 78 percent nitrogen, 21 percent oxygen, and 1 percent other ingredients envelops us. This atmosphere affects Earth's long-term climate and short-term local weather; shields us from nearly all harmful radiation coming from the Sun; and protects us from meteors as well—most of which burn up before they can strike the surface. Satellites have revealed that the upper atmosphere actually swells by day and contracts by night due to solar activity.

Our planet's rapid spin and molten nickel-iron core give rise to a magnetic field, which the solar wind distorts into a teardrop shape. The solar wind is a stream of charged particles continuously ejected from the Sun. The magnetic field does not fade off into space, but has definite boundaries. When charged particles from the solar wind become trapped in Earth's magnetic field, they collide with air molecules above our planet's magnetic poles. These air molecules then begin to glow and are known as the aurorae, or the Northern and Southern Lights.

Earth's land surfaces are also in motion. For example, the North American continent continues to move west over the Pacific Ocean basin, roughly at a rate equal to the growth of our fingernails. Earthquakes result when plates grind past one another, ride up over one another, collide to make mountains, or split and separate. These movements are known as plate tectonics. Developed within the last 30 years, this explanation has unified the results of centuries of study of our planet, long believed to be unmoving.

From the vantage point of space we are able to observe our planet globally, as we do other planets, using similar sensitive instruments to understand the delicate balance among its oceans, air, land, and life.

Fast Facts

Mean Distance from Sun	149,597,890 km (1 astronomical unit, or AU)
Orbital Period	365.26 days
Orbital Eccentricity	0.0167
Orbital Inclination to Ecliptic	0.00005°
Inclination of Equator to Orbit	23.45°
Rotational Period	23 h 56 m
Diameter	12,756 km
Mass	5.9742×10^{27} g
Density	5.515 g/cm^3
Gravity	980 cm/s^2
Atmosphere (primary components)	78% nitrogen, 21% oxygen, 1% other
Mean Temperature at Surface	15 °C
Number of Moons	1
Number of Rings	0

Significant Dates

1957 *Sputnik* (U.S.S.R.) becomes Earth's first artificial satellite.
1960 NASA launches *Tiros*, first weather satellite.
1968 *GOES* series of weather satellites begins.
1972 *Landsat* satellite series begins to observe Earth's land surfaces.
1991 *UARS* provides evidence that human-made chemicals are responsible for the Antarctic ozone hole.
1992 U.S./French satellite *TOPEX/Poseidon* details links between Earth's oceans and climate.
1999 *Terra* Earth-observing satellite begins studying global climate change.
2000 *Shuttle Radar Topography Mission (SRTM)* maps 80 percent of Earth's surface at 30-meter resolution.

About the Images

(Left) Earth is an ocean planet. The complex interplay between oceans and air affects our climate and weather (NOAA *GOES-7* false color).
(Right, top) Plants use chlorophyll during photosynthesis. Chlorophyll concentrations around the world indicate the distribution and abundance of vegetation. Since most animal life relies on vegetation for nutrition, directly or indirectly, these images are snapshots of Earth's biosphere (*SeaWiFS*).
(Right, center) The temperatures of the surfaces of Earth's seas are used to help us predict weather patterns, to track ocean currents, and to monitor El Niño and La Niña. Warm water (red) is higher, while cold water (blue) is lower (*Advanced Very High Resolution Radiometer [AVHRR]*).
(Right, bottom left) Spaceborne radar allows us to observe regions that are hard to reach. This false-color radar image of central Africa shows the Virunga Volcano chain along the borders of Rwanda, Zaire, and Uganda. This area is home to the endangered mountain gorillas (*Shuttle Imaging Radar-C*).
(Right, bottom right) Global maps of ozone in Earth's stratosphere show the role of chlorine monoxide in the destruction of stratospheric ozone, especially over the cold polar regions (*Microwave Limb Sounder on Upper Atmosphere Research Satellite*).

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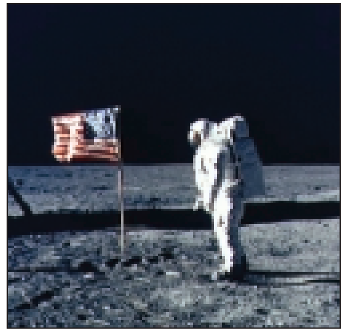
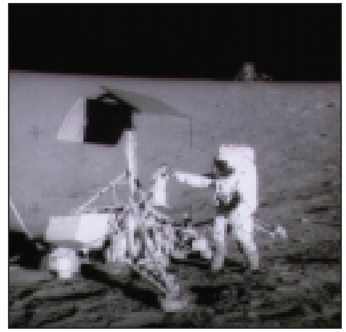
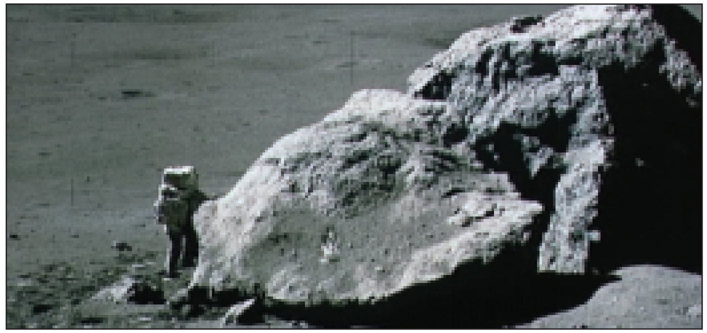
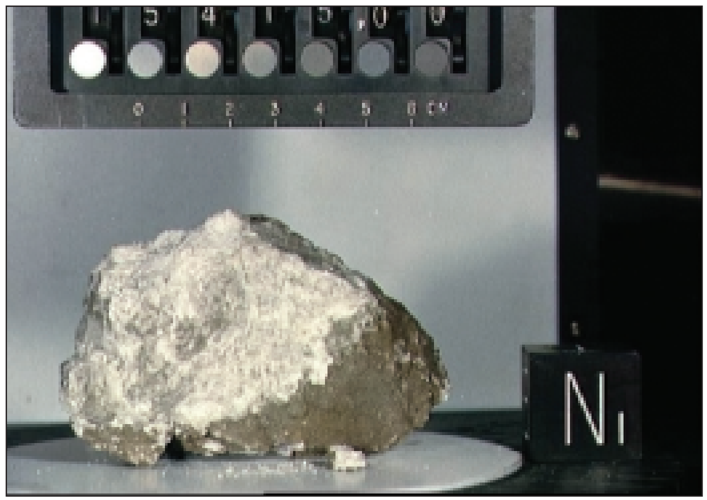
Moon









Moon

The regular daily and monthly rhythms of Earth's only natural satellite, the **MOON**, have guided timekeepers since ancient times. Its influence on Earth's cycles, notably tides, has also been charted by many cultures in many ages. More than 70 spacecraft have been sent to the Moon; 12 astronauts have walked upon its surface and brought back 382 kg of lunar rock and soil to Earth.

The presence of the Moon stabilizes Earth's wobble. This has led to a much more stable climate over billions of years, which may have affected the course of the development and growth of life on Earth.

How did the Moon come to be? The leading theory is that a Mars-sized body once hit Earth and the resulting debris (from both Earth and the impacting body) accumulated to form the Moon. Scientists believe that the Moon was formed approximately 4.5 billion years ago (the age of the oldest collected lunar rocks). When the Moon formed, its outer layers melted under very high temperatures, forming the lunar crust, probably from a global "magma ocean."

From Earth, we see the same face of the Moon all the time because the Moon rotates just once on its own axis in very nearly the same time that it travels once around Earth. This is known as "synchronous rotation." Patterns of dark and light features on the nearside have given rise to the fanciful "Man in the Moon" description. The light areas are lunar highlands. The dark features, called *maria*, are impact basins that were filled with dark lava between 4 and 2.5 billion years ago.

After this time of volcanism, the Moon cooled down, and has since been nearly unchanged, except for a steady rain of "hits" by meteorites and comets. The Moon's surface is charcoal gray and sandy, with much fine soil. This powdery blanket is called the lunar regolith, a term for mechanically produced debris layers on planetary surfaces. The regolith is thin, ranging from about 2 meters on the youngest maria to perhaps 20 meters on the oldest surfaces in the highlands.

Unlike Earth, the Moon does not have moving crustal plates or active volcanoes. However, seismometers planted by the Apollo astronauts in the 1970s have recorded small quakes at depths of several hundred kilometers. The quakes are probably triggered by tides resulting from Earth's gravitational pull. Small eruptions of gas from some craters, such as Aristarchus, have also been reported. Local magnetic areas have been detected around craters, but the Moon does not have a magnetic field resembling Earth's.

A surprising discovery from the tracking of the *Lunar Orbiter* spacecraft in the 1960s revealed strong areas of high gravitational acceleration located over the circular maria. These mass concentrations (mascons) may be caused by layers of denser, basaltic lavas that fill the mare basins.

In 1998, the *Lunar Prospector* spacecraft team reported finding water ice at both poles. Comet impacts deposited water on the Moon. Some of it migrated to very dark, very cold areas at the poles.

Much remains to be learned about our Moon. Researchers continue to study the samples and data returned by Apollo and other missions, as well as lunar meteorites.

Fast Facts

Mean Distance from Earth	384,400 km
Orbital Period	27.32 days
Orbital Eccentricity	0.05
Orbital Inclination to Ecliptic	18.3°–28.6°
Inclination of Equator to Orbit	6.67°
Rotational Period	27 d 7 h 41 m (synchronous)
Diameter	3,475 km
Mass	0.0123 of Earth's
Density	3.34 g/cm^3
Gravity	0.17 of Earth's
Surface Rocks	basaltic and anorthositic
Atmosphere	None
Mean Temperature at Surface	107 °C (day), -153 °C (night)

Significant Dates

1610	Italian astronomer Galileo Galilei made the first telescopic observations of the Moon.
1959–60	*Luna 1–3* (U.S.S.R) were the first to fly by, impact, and photograph the far side of the Moon.
1964	*Ranger 7* data indicated that the lunar surface would be suitable for a piloted landing.
1966	Soviet *Luna 9* made the first soft landing on the Moon.
1966–67	*Lunar Orbiters* photographically mapped the Moon.
1968	*Apollo 8*, first piloted flight to the Moon, circled 10 times before returning to Earth.
1969	*Apollo 11*, first human landing on the Moon, returned rock and soil samples.
1970	*Luna 16* was the first of 3 Soviet missions to use a robotic rover to return lunar soil samples.
1972	*Apollo 17* was the last of 6 *Apollo* missions to land astronauts and return samples from the Moon.
1994	*Clementine* conducted multispectral mapping and measured altitudes on the Moon.
1998	*Lunar Prospector* made a geochemical map of the Moon and discovered ice at both poles.

About the Images

(Left) The familiar face of the Moon, taken by *Apollo 11* astronauts on their way home, shows the dark maria and lighter highlands.

(Right, top center) *Apollo 11* astronaut Edwin Aldrin stands facing the U.S. flag on the Moon.

(Right, top right) In 1969, *Apollo 12* astronaut Pete Conrad says hello to *Surveyor 3*, which landed in 1967.

(Right, center) *Apollo 17* scientist-astronaut Harrison Schmitt stands next to a huge, split boulder at the Taurus-Littrow landing site on the last human mission to the moon in 1972.

(Right, bottom) Close-up view of *Apollo 15* lunar sample number 15415 in the Non-sterile Nitrogen Processing Line in the Lunar Receiving Laboratory at the Manned Spacecraft Center. This sample is the white anorthositic rock (nicknamed the Genesis Rock) that is 4.5 billion years old—as old as Earth.

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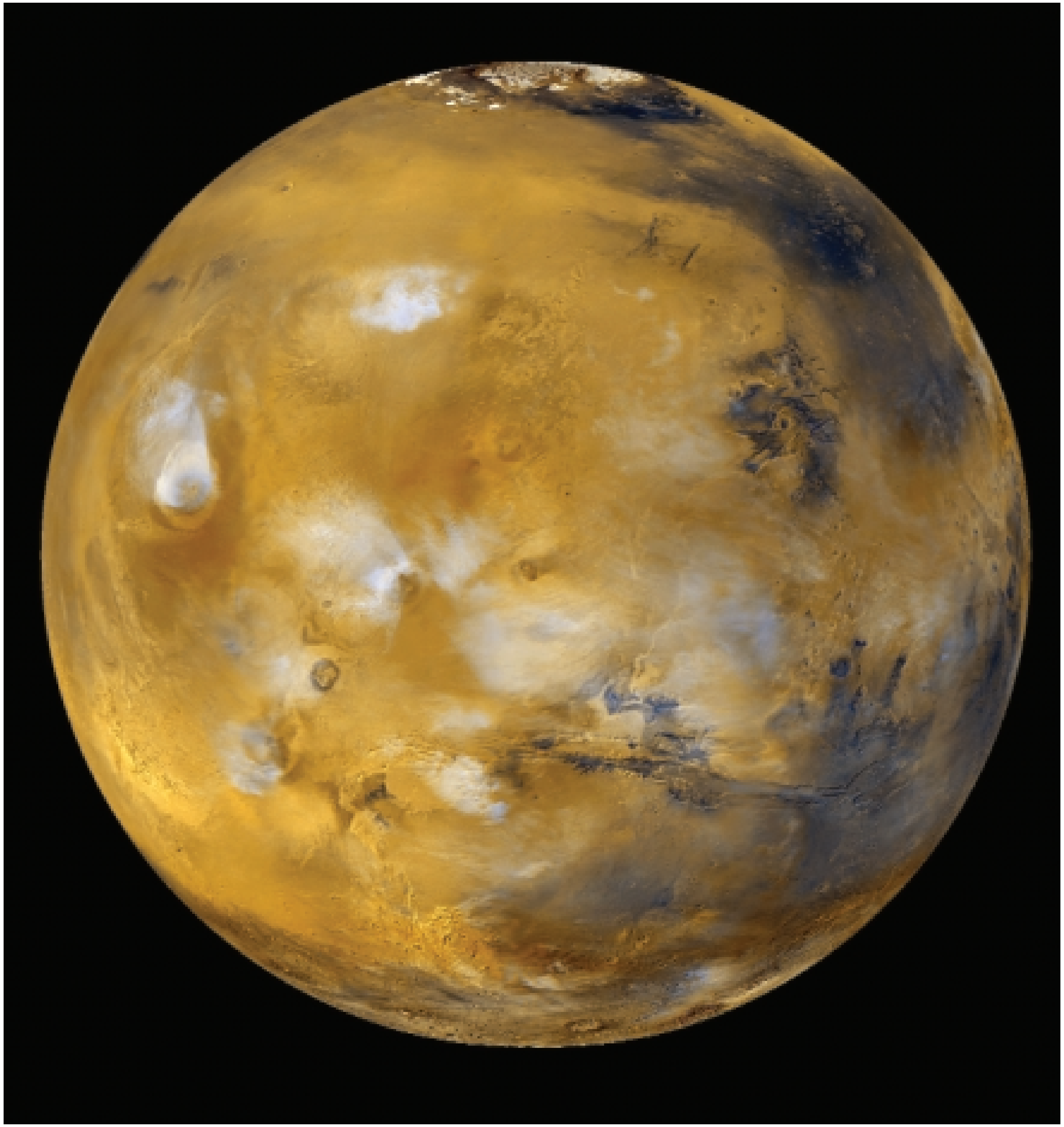
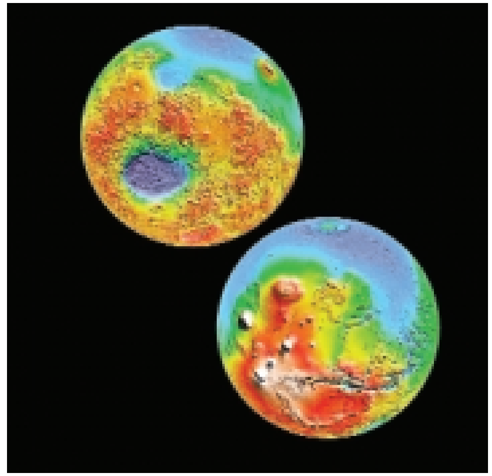
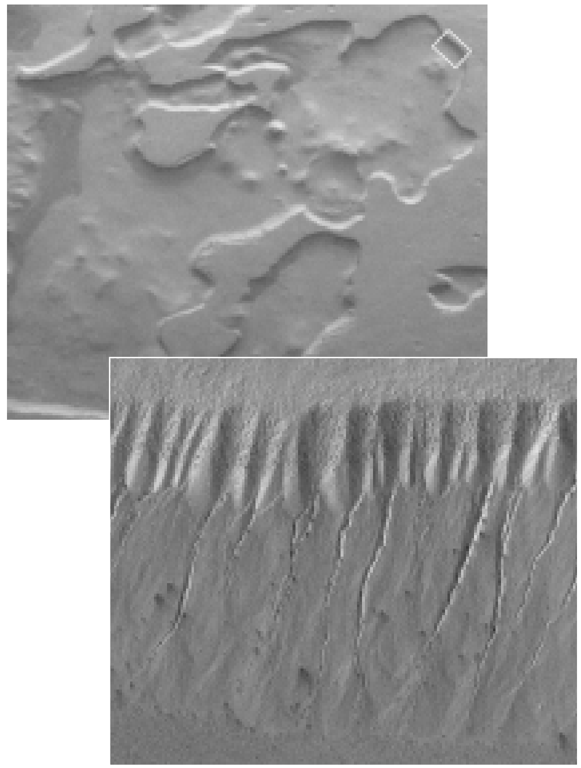
Mars ♂







Mars ♂

The red planet **MARS** has inspired wild flights of imagination over the centuries, as well as intense scientific interest. Whether fancied to be the source of hostile invaders of Earth, the home of a dying civilization, or a rough-and-tumble mining colony of the future, Mars provides fertile ground for science fiction writers, based on seeds planted by centuries of scientific observations.

We know that Mars is a small rocky body once thought to be very Earth-like. Like the other "terrestrial" planets—Mercury, Venus, and Earth—its surface has been changed by volcanism, impacts from other bodies, movements of its crust, and atmospheric effects such as dust storms. It has polar ice caps that grow and recede with the change of seasons; areas of layered soils near the Martian poles suggest that the planet's climate has changed more than once, perhaps caused by a regular change in the planet's orbit. Martian tectonism—the formation and change of a planet's crust—differs from Earth's. Where Earth tectonics involve sliding plates that grind against each other or spread apart in the seafloors, Martian tectonics seem to be vertical, with hot lava pushing upwards through the crust to the surface. Periodically, great dust storms engulf the entire planet. The effects of these storms are dramatic, including giant dunes, wind streaks, and wind-carved features.

Scientists believe that 3.5 billion years ago, Mars experienced the largest known floods in the solar system. This water may even have pooled into lakes or shallow oceans. Yet the central question about Mars remains: where is the water? Where did the ancient flood water come from, how long did it last, and where did it go? At the present, Mars is too cold and its atmosphere is too thin to allow liquid water to exist at the surface for long. We know that some water exists today frozen in the polar ice caps, and enough water exists to form ice clouds, but the quantity of water required to carve Mars' great channels and flood plains is not evident on the surface today. Recent images from NASA's *Mars Global Surveyor* spacecraft suggest that underground reserves of water may break through the surface as springs. Unraveling the story of water on Mars is important to unlocking its past climate history, which will help us understand the evolution of all planets, including our own. Water is also believed to be a central ingredient for the initiation of life; the evidence of past or present water on Mars is expected to hold clues about past or present life on Mars, as well as the potential for life elsewhere in the universe. And, before humans can safely go to Mars, we need to know much more about the planet's environment, including the availability of resources such as water.

Mars has some remarkable geological characteristics, including the largest volcanic mountain in the solar system, Olympus Mons (27 km high and 600 km across); volcanoes in the northern Tharsis region that are so huge they deform the planet's roundness; and a gigantic equatorial rift valley, the Valles Marineris. This canyon system stretches a distance equivalent to the distance from New York to Los Angeles; Arizona's Grand Canyon could easily fit into one of the side canyons of this great chasm.

Mars also has two small moons, Phobos and Deimos. Although no one knows how they formed, they may be asteroids snared by Mars' gravity.

Fast Facts

Namesake	Roman God of War
Mean Distance from Sun	227,936,640 km
Orbital Period	1.88 years
Orbital Eccentricity	0.093
Orbital Inclination to Ecliptic	1.85°
Inclination of Equator to Orbit	25.19°
Rotational Period	24 h 37 m
Diameter	6,794 km
Mass	0.11 of Earth's
Density	3.94 g/cm^3
Gravity	0.38 of Earth's
Atmosphere (primary components)	95% carbon dioxide
Temperature Range	–143 °C to +17 °C
Moons (2) in Increasing Distance from Mars	Phobos, Deimos
Number of Rings	0

Significant Dates

1965	*Mariner 4* made first close-up pictures of the surface during flyby.
1969	*Mariner 6* and *Mariner 7* flybys resulted in high-resolution images of the equatorial region and southern hemisphere.
1971	*Mariner 9* became first satellite to orbit another planet.
1973	U.S.S.R. *Mars 3* and *Mars 5* first attempt to land on Mars.
1976	U.S.A. *Vikings 1* and *2* orbited Mars. *Viking Lander 1* provided first sustained surface science. *Viking Lander 2* discovered water frost on the surface.
1996	Possible microfossil found in Martian meteorite ALH84001.
1997	*Mars Pathfinder* lands on Mars. *Sojourner Rover* explores Ares Vallis area for three months.
1997–present	*Mars Global Surveyor* maps the surface of Mars from orbit.
2001	Mars *Odyssey* orbiter goes to Mars.

About the Images

(Left) Mars is about half the diameter of Earth. Here, bluish-white water ice clouds hang above the Tharsis volcanoes. The northern polar cap is visible, as is Valles Marineris, a 4,000-km-long canyon system just below the equator and to the right of center (NASA/JPL/MSSS *Mars Global Surveyor*).
(Right, top) Color-coded topography maps show the high (red and white) and low (blue) areas on Mars. The southern hemisphere is heavily cratered and high, while the northern hemisphere is lower and smoother. The large Hellas basin is seen in the southern hemisphere of the top image; the three Tharsis volcanoes, Olympus Mons, and the Valles Marineris canyon system can be seen in the lower image (NASA/JPL/GSFC *Mars Orbiter Laser Altimeter*).
(Right, bottom) Gullies with very sharp, deep, V-shaped channels on the walls of a pit might have been caused by geologically recent seepage and runoff of liquid water on Mars (NASA/JPL/MSSS *Mars Global Surveyor*). The small white box in the context frame (upper right corner) shows the location of the high-resolution view (NASA/*Viking*).

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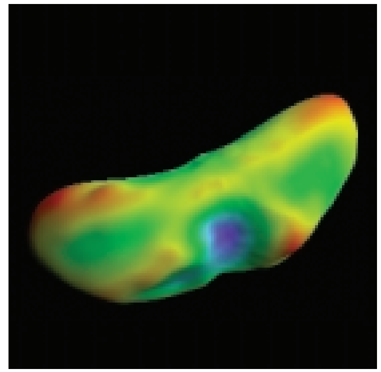
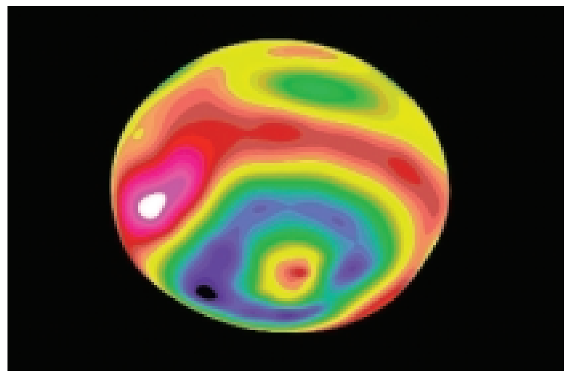
Asteroids





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Asteroids

ASTEROIDS are rocky fragments left over from the formation of the solar system about 4.6 billion years ago. Most of these fragments of ancient space rubble—sometimes referred to by scientists as minor planets—can be found orbiting the Sun in a belt between Mars and Jupiter. This region in our solar system, called the Asteroid Belt or Main Belt, probably contains millions of asteroids ranging widely in size from Ceres, which at 940 km in diameter is about one-quarter the diameter of our Moon, to bodies that are less than 1 km across. There are more than 20,000 numbered asteroids.

As asteroids revolve around the Sun in elliptical orbits, giant Jupiter's gravity and occasional close encounters with Mars or with another asteroid change the asteroids' orbits, knocking them out of the Main Belt and hurling them into space across the orbits of the planets. For example, Mars' moons Phobos and Deimos may be captured asteroids. Scientists believe that stray asteroids or fragments of asteroids have slammed into Earth in the past, playing a major role both in altering the geological history of our planet and in the evolution of life on it. The extinction of the dinosaurs 65 million years ago has been linked to a devastating impact near the Yucatan peninsula in Mexico.

Asteroids were first observed with telescopes in the early 1800s, and in 1802, the astronomer William Herschel first used the word "asteroid," which means "starlike" in Greek, to describe these celestial bodies. Most of what we have learned about asteroids in the past 200 years has been derived from telescopic observations. Ground-based telescopes are used to watch asteroids that orbit close to Earth, not only to detect new ones or keep track of them, but also to watch for any asteroids that might collide with Earth in the future. Scientists define near-Earth asteroids (NEAs) as those whose orbits never take them farther than about 195 million kilometers from the Sun.

In the last few decades, astronomers have used instruments called spectroscopes to determine the chemical and mineral composition of asteroids by analyzing the light reflected off their surfaces. Scientists also examine meteorites—the remains of comets or asteroids that can be found on Earth—for clues to the origin of these bodies. About three-quarters of asteroids are extremely dark and are similar to carbon-rich meteorites called carbonaceous chondrites (C-type). About one-sixth of asteroids are reddish, stony-iron bodies (S-type).

In 1997, instruments on the *Hubble Space Telescope* mapped Vesta, one of the largest asteroids, and found an enormous crater formed a billion years ago. Interestingly, Vesta is an uncommon asteroid type, yet meteorites having the same composition have been found on Earth. Could these be remnants from the collision that created Vesta's giant crater?

NASA's *Galileo* spacecraft was the first to observe an asteroid close-up, flying by main-belt asteroids Gaspra and Ida in 1991 and 1993, respectively. Gaspra and Ida proved to be irregularly shaped objects, rather like potatoes, riddled with craters and fractures, 19 km long and 52 km long respectively. Galileo also discovered that Ida has its own moon, Dactyl, a tiny body in orbit around the asteroid that may be a fragment from past collisions.

NASA's *Near-Earth Asteroid Rendezvous (NEAR)* mission was the first dedicated scientific mission to an asteroid. The *NEAR Shoemaker* spacecraft caught up with asteroid Eros in February 2000 and orbited the small body for a year, studying its surface, orbit, mass, composition, and magnetic field. In February 2001, mission controllers guided the spacecraft to the first-ever landing on an asteroid.

Fast Facts
(for some representative asteroids)

	Eros	Gaspra	Vesta	Ceres	Ida
Mean Distance from Sun (AU)	1.458	2.209	2.36	2.768	2.86
Orbital Period (yrs)	1.76	3.29	3.63	4.6	4.84
Orbital Eccentricity	0.26	0.17	0.09	0.08	0.05
Orbital Inclination to Ecliptic	10.8°	4.1°	7.1°	10.6°	1.1°
Rotational Period (hrs)	5.27	7.402	5.342	9.075	4.63
Dimensions	35 x 13 km	18 x 11 x 9 km	530 km diameter	933 km diameter	58 x 23 km
Asteroid Type	S	S	V	G	S

An Astronomical Unit (AU) is the average distance between the Sun and Earth, about 150,000,000 kilometers.

Some Asteroid Types:
S—Stony irons and ordinary chondrites; C—Carbonaceous chondrites; V—Like S, more pyroxene; G—Like C, brighter, very strong UV absorption.

Significant Dates

1801	First asteroid, Ceres, discovered by Piazzi.
1807	Vesta discovered by Olbers.
1884	Asteroid Ida discovered by Palisa.
1898	Asteroid Eros discovered by Witt.
1916	Asteroid Gaspra discovered by Neujmin.
1991	*Galileo* captures first close-up images of asteroid (Gaspra).
1994	*Galileo* discovers first satellite (Dactyl) of an asteroid (Ida).
1996	*NEAR Shoemaker* studies asteroid Mathilde.
1997	*Hubble Space Telescope* studies Vesta.
2000–01	*NEAR Shoemaker* orbits Eros for one year and then lands.

About the Images

(Upper left) Asteroid Eros is about 33 kilometers long (*NEAR Shoemaker*).
(Upper right) Surface of Eros is covered in rocks of all shapes and sizes (*NEAR Shoemaker*).
(Right center) Color-coded map shows uphill (red) and downhill (blue) areas on Eros (*NEAR Shoemaker*).
(Lower left) Mars' two moons Phobos (left) and Deimos (right) may be captured asteroids. Asteroid Gaspra (top) is shown at same scale.
(Lower center) Asteroid Ida and its moon Dactyl (*Galileo*).
(Lower right) Color-coded topography map of asteroid Vesta clearly shows a large crater with a central peak (blue is low, red is high) (*Hubble Space Telescope*).

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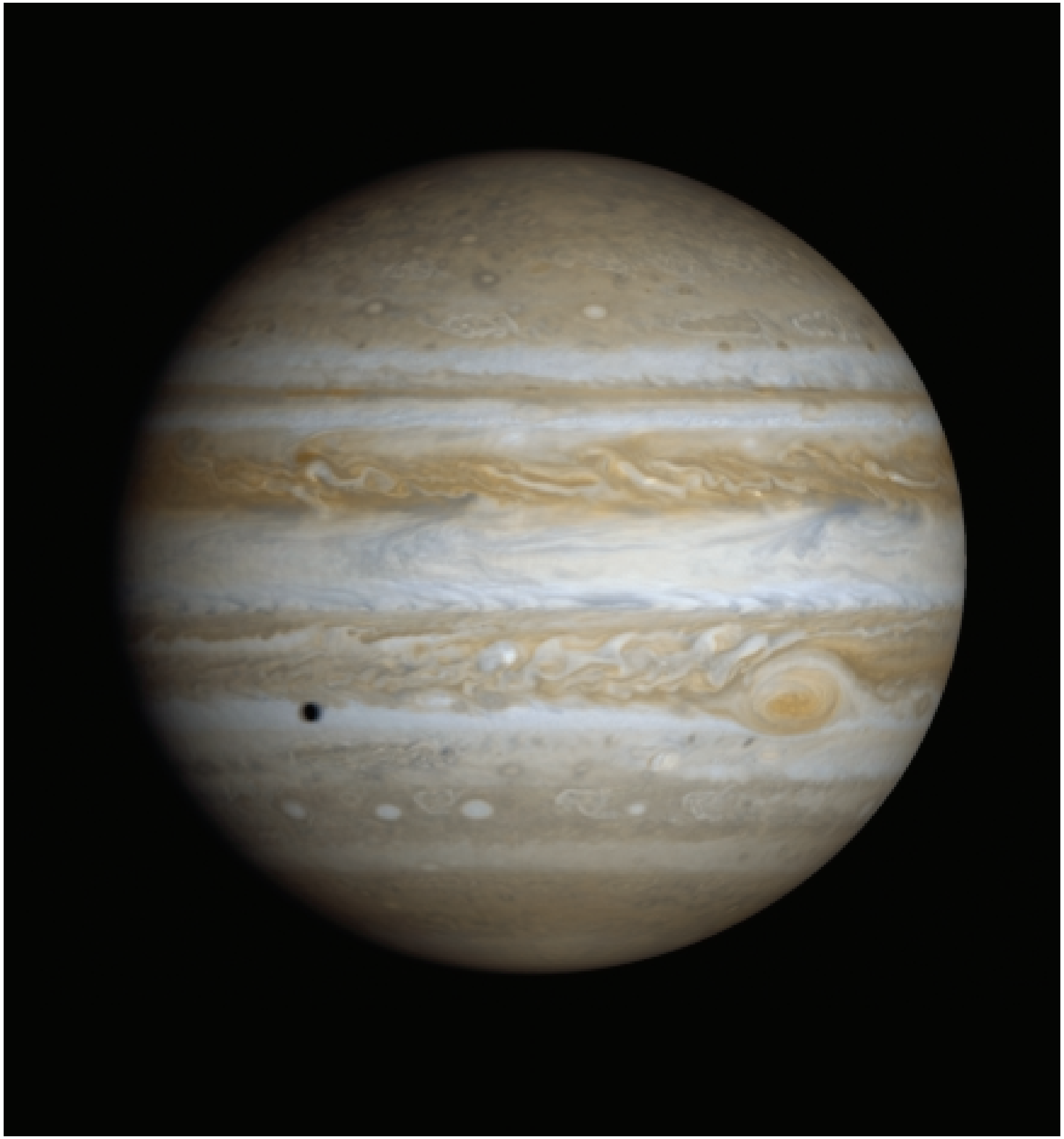

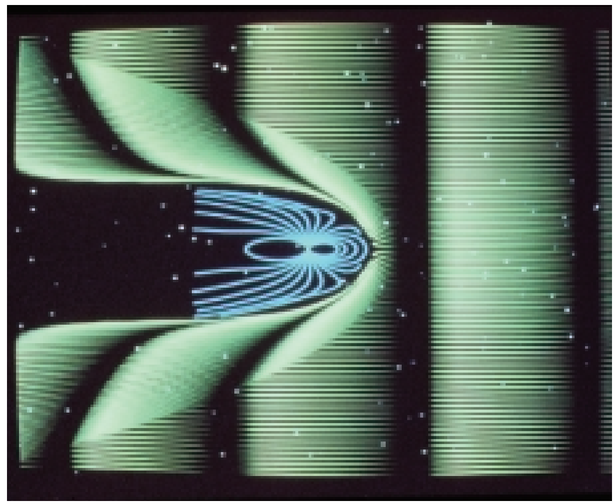

National Aeronautics and
Space Administration

Jupiter ♃

With its numerous moons and several rings, the **JUPITER** system is a "mini-solar system." Jupiter is the most massive planet in our solar system, and in composition it resembles a small star. In fact, if Jupiter had been between fifty and one hundred times more massive, it would have become a star rather than a planet.

On January 7, 1610, while skygazing from his garden in Padua, Italy, astronomer Galileo Galilei was surprised to see four small "stars" near Jupiter. He had discovered Jupiter's four largest moons, now called Io, Europa, Ganymede, and Callisto. Collectively, these four moons are known today as the Galilean satellites.

Galileo would be astonished at what we have learned about Jupiter and its moons in the past 30 years. Io is the most volcanically active body in our solar system. Ganymede is the largest planetary moon and has its own magnetic field. A liquid ocean may lie beneath the frozen crust of Europa. An icy ocean may also lie beneath the crust of Callisto. Jupiter also has at least 24 smaller moons. The 20 outer moons are probably asteroids captured by the giant planet's gravity.

At first glance, Jupiter appears striped. These stripes are dark belts and light zones created by strong east-west winds in Jupiter's upper atmosphere. Within these belts and zones are storm systems that have raged for years. The southern hemisphere's Great Red Spot has existed for at least 100 years, and perhaps longer, as Galileo reported seeing a similar feature nearly 400 years ago. Three Earths could fit across the Great Red Spot.

Jupiter's core is probably not solid but a dense, hot liquid with a consistency like thick soup. The pressure inside Jupiter may be 30 million times greater than the pressure at Earth's surface.

As Jupiter rotates, a giant magnetic field is generated in its electrically conducting liquid interior. Trapped within Jupiter's magnetosphere—the area in which magnetic field lines encircle the planet from pole to pole—are enough charged particles to make the inner portions of Jupiter's magnetosphere the most deadly radiation environment of any of the planets, both for humans and for electronic equipment. The "tail" of Jupiter's magnetic field—that portion stretched behind the planet as the solar wind rushes past—has been detected as far as Saturn's orbit. Jupiter's rings and moons are embedded in an intense radiation belt of electrons and ions trapped in the magnetic field. The Jovian magnetosphere, which comprises these particles and fields, balloons one to three million kilometers toward the Sun and tapers into a windsock-shaped tail extending more than one billion kilometers behind Jupiter—as far as Saturn's orbit.

Discovered in 1979 by NASA's *Voyager 1* spacecraft, Jupiter's rings were a surprise: a flattened main ring and an inner cloud-like ring, called the halo, are both composed of small, dark particles. A third ring, known as the gossamer ring because of its transparency, is actually three rings of microscopic debris from three small moons: Amalthea, Thebe, and Adrastea. Jupiter's ring system may be formed by dust kicked up as interplanetary meteoroids smash into the giant planet's four small inner moons. The main ring probably comes from the tiny moon Metis.

In December 1995, NASA's *Galileo* spacecraft dropped a probe into Jupiter's atmosphere. Carrying six scientific instruments, the probe survived the crushing pressure and searing heat for nearly an hour, collecting the first direct measurements of Jupiter's atmosphere, the first real data about the chemistry of a gas planet. Following the release of the probe, the *Galileo* spacecraft began a multi-year orbit of Jupiter, observing each of the largest moons from close range several times.

Fast Facts

Namesake	King of the Roman Gods
Mean Distance from Sun	778.4 million km
Orbital Period	11.86 years
Orbital Eccentricity	0.048
Orbital Inclination to Ecliptic	1.3°
Inclination of Equator to Orbit	3.12°
Rotational Period	9 h 55 m
Diameter	142,984 km
Mass	318 times Earth's
Density	1.33 g/cm^3
Gravity	2.36 of Earth's
Atmosphere (Primary Components)	Hydrogen and Helium
Atmospheric Temperature at 1-bar Pressure Level	165 K
Known Moons (28) in Increasing Distance from Jupiter	Metis, Adrastea, Amalthea, Thebe, Io, Europa, Ganymede, Callisto, S/1975 J1, Leda, Himalia, Lysithea, Elara, S/2000 J1, J3, J7, J5, Ananke, S/2000 J6, J4, J9, J10, Carme, Pasiphae, S/2000 J2, J8, Sinope, S/1999 J1
Rings	1 (4 parts)

Significant Dates

1610	Italian astronomer Galileo Galilei discovers four moons orbiting Jupiter (Io, Europa, Ganymede, and Callisto—the Galilean satellites).
1973	*Pioneer 10*, the first spacecraft to reach Jupiter, passes within 130,354 km of Jupiter's cloud tops.
1974	*Pioneer 11* passes within 43,000 km of Jupiter's cloud tops, providing first images of polar regions.
1979	*Voyager 1* passes within 350,000 km of Jupiter's center and discovers a faint ring and three moons.
1979	*Voyager 2* passes within 650,000 km of Jupiter's center, providing detailed imagery of Jovian ring and Io volcanism.
1992	*Ulysses* uses Jupiter's gravity to enter solar polar orbit.
1995	*Galileo* arrives at Jupiter; atmospheric entry probe survives to pressure depth of 23 bars.
1995–present	*Galileo* orbits within Jupiter's system, studying planet, rings, satellites, and magnetosphere.
2000–01	*Cassini* observes Jupiter while en route to Saturn.

About the Images

(Left) Strong east-west winds create latitudinal bands in Jupiter's atmosphere (*Cassini*).

(Right, top) Two of Jupiter's moons, volcanic Io (above the Great Red Spot) and icy Europa (right) are seen as they orbit about 350,000 and 600,000 km (respectively) above the planet's clouds (*Voyager 1*).

(Right, center) Very small dust-sized particles in Jupiter's main ring and a hint of the surrounding halo can be seen in this composite of several images (*Galileo and Voyager*).

(Right, bottom) Artist's conception of magnetic field lines (blue) extending from pole to pole form a "cage" around Jupiter, which is stretched behind the planet as the solar wind (green) rushes past.

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National Aeronautics and
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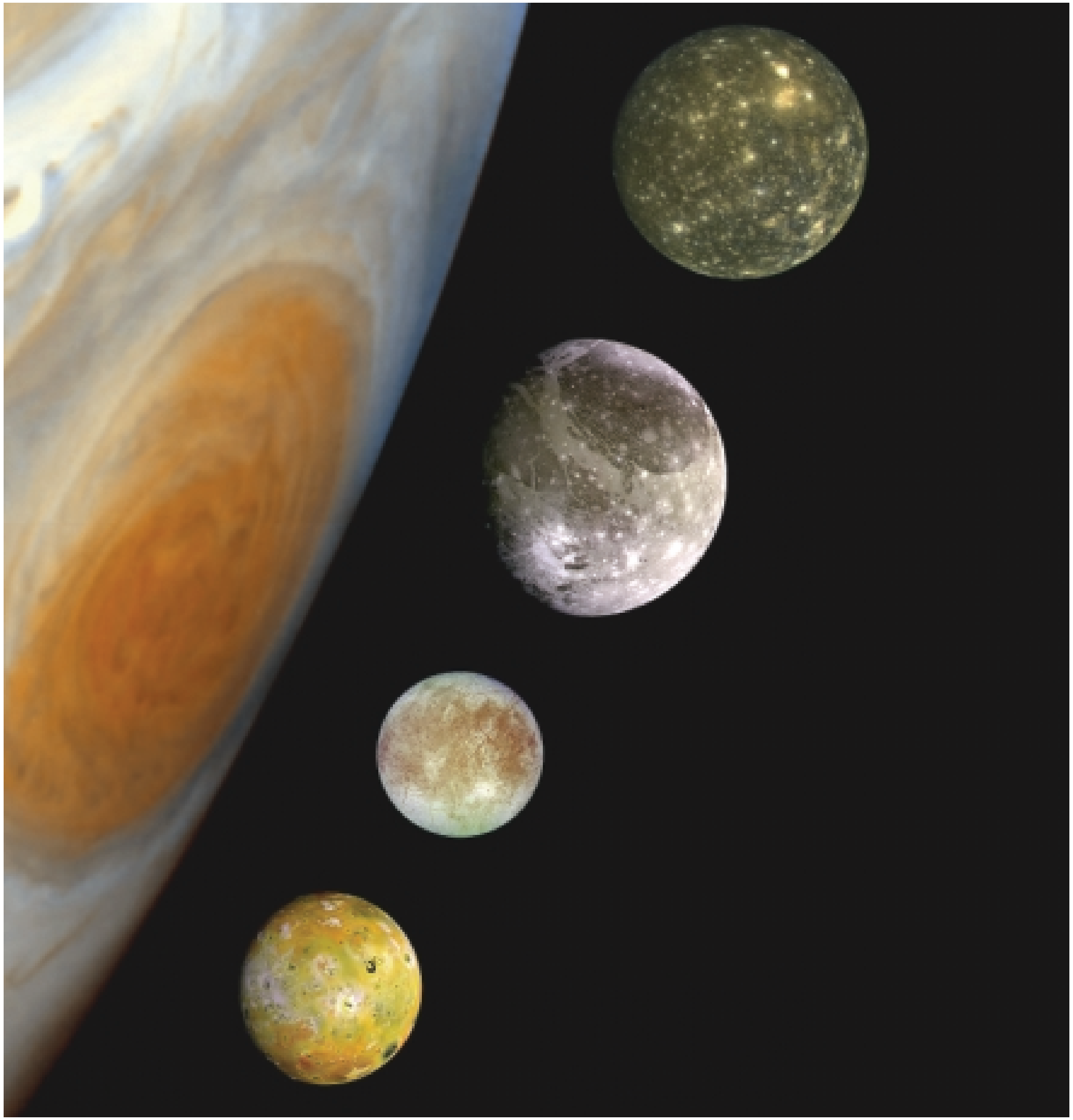
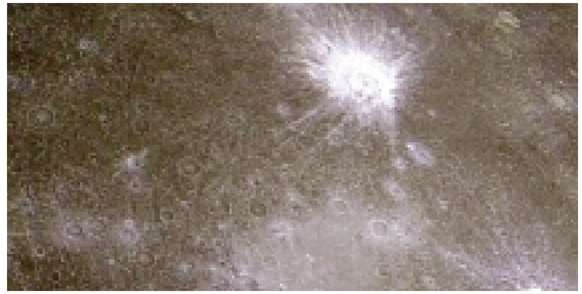
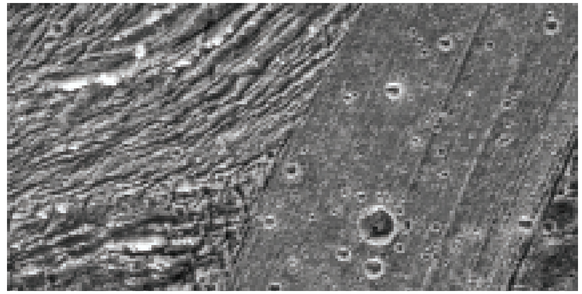
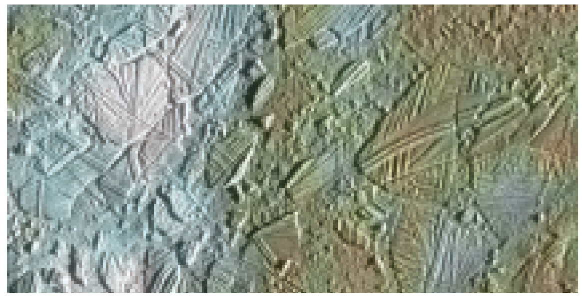
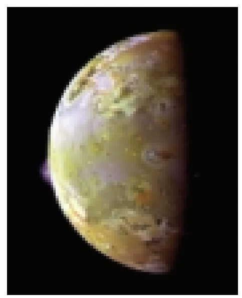
Moons of Jupiter

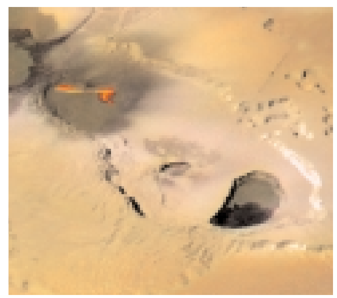












National Aeronautics and
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Moons of Jupiter

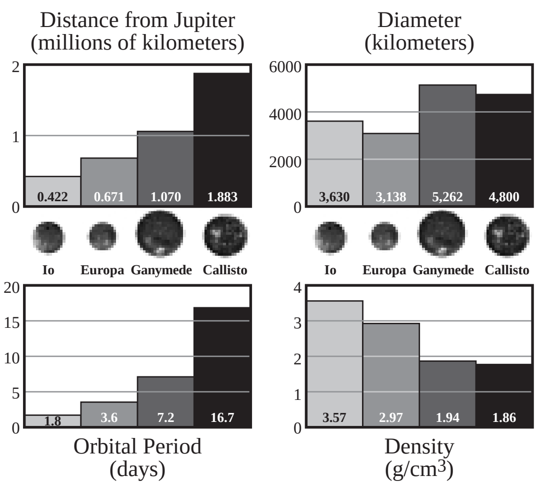
The planet Jupiter's four largest moons are called the Galilean satellites, after Italian astronomer Galileo Galilei who observed them in 1610. The moons were also observed then by German astronomer Simon Marius. These moons, named **IO**, **EUROPA**, **GANYMEDE**, and **CALLISTO**, are particularly intriguing since each has its own amazing distinction in our solar system. Io is the most volcanically active body in the solar system, and parts of its surface change within weeks. Europa's cracked surface is mostly water ice, and there is strong evidence that it may be covering an ocean of water or slushy ice. Ganymede is the largest moon in the solar system (larger than even the planet Mercury), and it is the first moon known to have its own magnetic field. Callisto is extremely heavily cratered but has surprised scientists with its lack of very small craters that should be visible in *Galileo*'s closeup images—they appear to be covered with fine dust.

Though distinctive, the Galilean moons also have much in common. The surfaces of the outermost three moons are mostly water ice, mixed with rocky, probably carbon-rich, material. Io's surface is mainly sulfur in different colorful forms including sulfur dioxide. As Io travels in its slightly elliptical orbit, Jupiter's immense gravity causes tides in the solid surface 100 meters high on Io, generating enough heat to drive the volcanic activity and drive off any water. Io's volcanoes are driven by hot silica, not water. Io, Europa, and Ganymede all have a layered interior structure (as does Earth). Europa and Ganymede both have a core; a rock envelope around the core; a thick, soft ice layer; and a thin crust of impure water ice. Io has a core, and a mantle of at least partially molten rock, topped by a crust of solid rock coated with sulfur compounds. On the other hand, Callisto appears to be an ice-rock mix both inside and out. Under the influence of Jupiter's and each other's gravity, the Galilean moons all keep the same face towards Jupiter as they orbit (as does our moon towards Earth). This means that each of the moons turns only once on its axis for every orbit about Jupiter.

Galileo proposed that these moons be called the "Medicean stars" in honor of his patron, Cosimo II de Medici; Marius named the moons Io, Europa, Ganymede, and Callisto after the lovers of the Roman god Jupiter (who was known to the Greeks as Zeus). They continued to be studied from Earth through telescopes until the two *Pioneer* (in 1973–74) and two *Voyager* (in 1979) spacecraft offered striking color views and a global perspective from their midrange flybys while surveying parts of the outer solar system. At present, the *Galileo* spacecraft flies in repeated elliptical orbits around Jupiter, flying as low as 261 kilometers over the surface of the Galilean moons. That's lower than the average Space Shuttle orbit over Earth, and much lower than most communications satellites. These close approaches result in images with unprecedented detail of selected portions of the moons' surfaces.

Close-up images taken by the *Galileo* spacecraft of portions of Europa's surface show places where ice has broken up and appeared to float apart, and where liquid seems to have come from below and frozen smoothly on the surface. The low number of craters on Europa leads scientists to believe that the ocean existed in recent geologic history and may still exist today. The heat needed to melt the ice in a place so far from the Sun is thought to come from inside of Europa, from a milder form of the tidal forces that drive Io's volcanoes.

Fast Facts



Significant Dates

1610 Italian astronomer Galileo Galilei and German astronomer Simon Marius independently discover four moons orbiting Jupiter.
1973 *Pioneer 10* is the first spacecraft to cross the asteroid belt and fly by Jupiter.
1974 *Pioneer 11* flies by Jupiter.
1979 *Voyagers 1* and *2* discover Io's volcanoes and Jupiter's ring.
1995 *Galileo* spacecraft drops probe into Jupiter's atmosphere and begins orbiting Jupiter.
2000–01 *Cassini* and *Galileo* spacecraft jointly observe Jupiter.

About the Images

(Left) In this composite of images, Jupiter's four largest moons are shown to scale, in order of increasing distance away from Jupiter (from bottom, Io, Europa, Ganymede, and Callisto). The limb (edge) of the gaseous giant planet in the region of the Great Red Spot is shown for comparison.

(Right) The insets of the surfaces of the moons show that each is unique.
(Bottom) On **Io**, a volcanic plume of cold sulfur dioxide gas and "snow" rises 140 km above the moon's surface. The closeup shows Tvashtar Catena, a chain of volcanic calderas, in enhanced color with the bright lava curtain (a chain of lava fountains) and surface flows added by the *Galileo* scientists, based on their knowledge of the area. Fountains of lava rise to heights of up to 1.5 km above the surface. The elongated caldera in the center of the image is almost surrounded by a mesa that is about 1 km high.
(Bottom, middle) On **Europa**, ice rafts the size of small towns (up to 13 km long) appear to have broken apart and "rafted" on soft ice or ice-crusted water. This suggests the presence of an ocean underneath Europa's icy surface.
(Top, middle) Ganymede has many diverse types of terrain, including this area of Nicholson Regio and Arbela Sulcus. The bright terrain of Arbela Sulcus is the youngest terrain here, slicing through the center of the image. It is finely striated and relatively lightly cratered. To the east (right) is the oldest terrain in this area, rolling and relatively densely cratered Nicholson Regio. To the west (left) is a region of highly deformed grooved terrain, intermediate in relative age. In this area of grooved terrain, stretching and normal faulting of Nicholson Regio has deformed it beyond recognition.
(Top) Callisto is famous for its numerous and varied craters. This multi-ringed impact crater named Asgard is surrounded by concentric rings up to 1,700 km in diameter. Newer craters, such as Burr in the upper right, are brighter because they expose fresh ice.
(All images by NASA/JPL/*Galileo*.)

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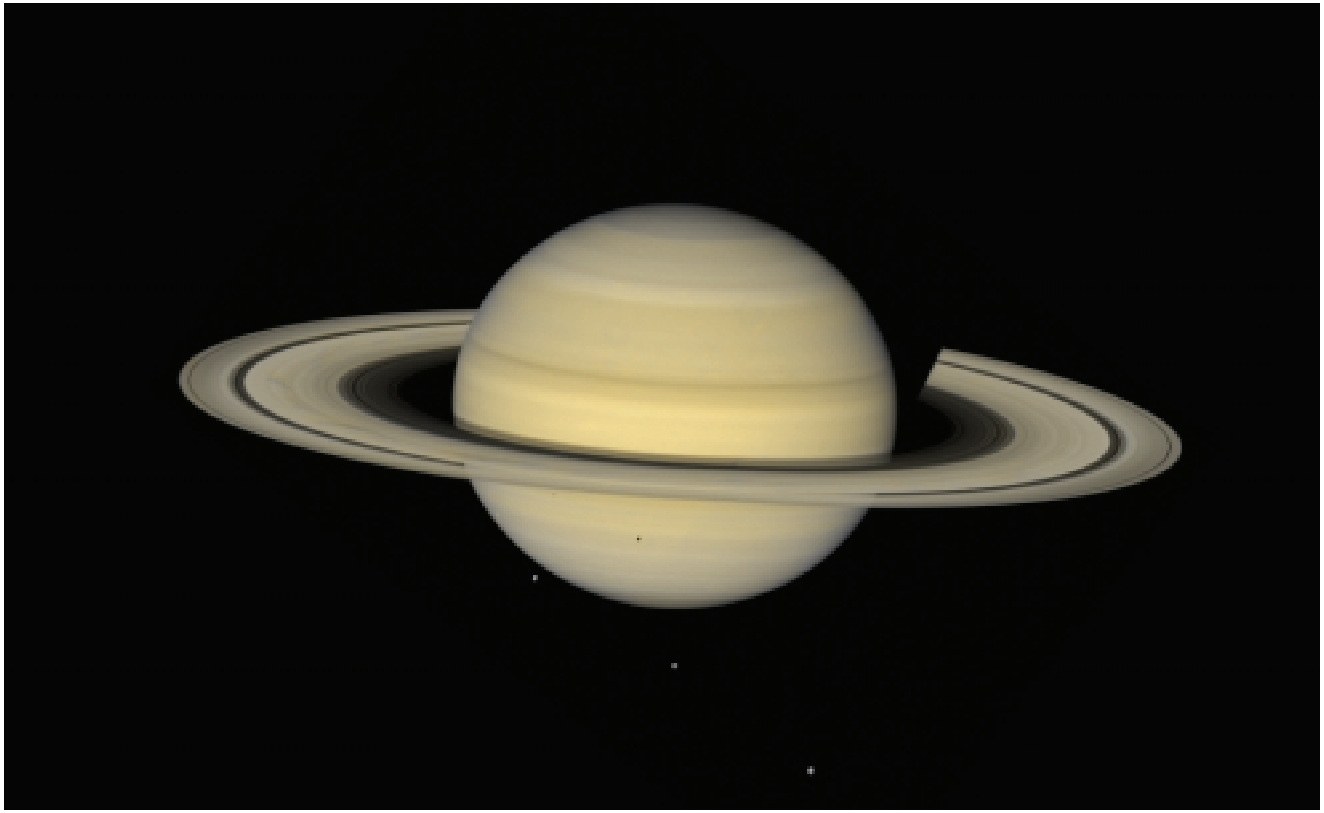
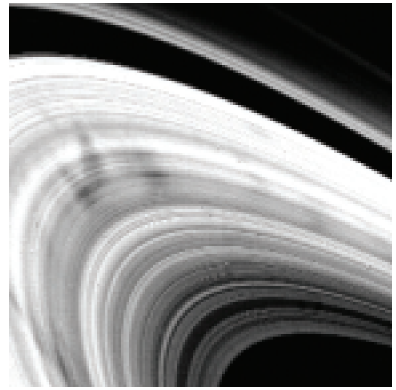
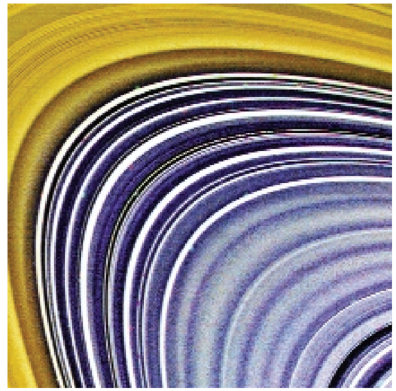
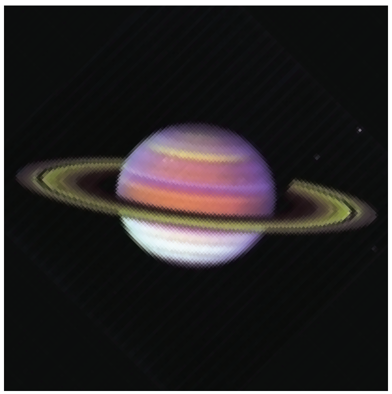
National Aeronautics and Space Administration

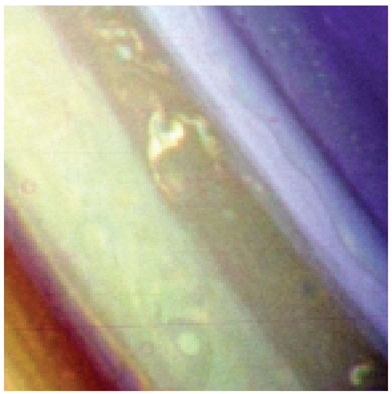
Saturn ♄











National Aeronautics and Space Administration

Saturn ♄

SATURN is the most distant of the five planets known to ancient stargazers. In 1610, Italian Galileo Galilei was the first astronomer to gaze at Saturn through a telescope. To his surprise, he saw a pair of objects on either side of the planet, which he later drew as "cup handles" attached to the planet on each side. In 1659, Dutch astronomer Christiaan Huygens announced that this was a ring encircling the planet. In 1675, Italian-born astronomer Jean Dominique Cassini discovered a gap between what are now called the A and B rings.

Like the other giant planets—Jupiter, Uranus, and Neptune—Saturn is a gas giant made mostly of hydrogen and helium. Its volume is 755 times greater than Earth's. Winds in the upper atmosphere reach 500 meters per second in the equatorial region. (In contrast, the strongest hurricane-force winds on Earth top out at about 110 meters per second.) These super-fast winds, combined with heat rising from within the planet's interior, cause the yellow and gold bands visible in its atmosphere.

Saturn's ring system is the most extensive and complex in our solar system; it extends hundreds of thousands of kilometers from the planet. In fact, Saturn and its rings would just fit in the distance between Earth and the Moon. In the early 1980s, NASA's two *Voyager* spacecraft revealed that Saturn's rings are made mostly of water ice, and they found "braided" rings, ringlets, and "spokes"—dark features in the rings that seem to circle the planet at a different rate from that of the surrounding ring material. Some of the small moons orbit within the ring system as well. Material in the rings ranges in size from a few micrometers to several tens of meters.

Saturn has at least 30 satellites. The largest, Titan, is a bit bigger than the planet Mercury. Titan is shrouded in a thick nitrogen-rich atmosphere that might be similar to what Earth's was like long ago. Further study of this moon promises to reveal much about planetary formation and, perhaps, about the early days of Earth as well.

In addition to Titan, Saturn has many smaller "icy" satellites. From Enceladus, which shows evidence of surface changes, to Iapetus, with one hemisphere darker than asphalt and the other as bright as snow, each of Saturn's satellites is unique.

Saturn, the rings, and many of the satellites lie totally within Saturn's enormous magnetosphere, the region of space in which the behavior of electrically charged particles is influenced more by Saturn's magnetic field than by the solar wind. Recent images by NASA's *Hubble Space Telescope* show that Saturn's polar regions have aurorae similar to Earth's Northern and Southern Lights. Aurorae occur when charged particles spiral into a planet's atmosphere along magnetic field lines.

The next chapter in our knowledge of Saturn is already under way, as the *Cassini/Huygens* spacecraft began its journey to Saturn in October 1997 and will arrive on July 1, 2004. The *Huygens* probe will descend through Titan's atmosphere in late November 2004 to collect data on the atmosphere and surface of the moon. *Cassini* will orbit Saturn more than 70 times during a four-year study of the planet, its moons, rings, and magnetosphere. *Cassini/Huygens* is a joint NASA/European Space Agency mission.

Fast Facts

Namesake	Roman God of Agriculture
Mean Distance from Sun	1.427 billion km
Orbital Period	29.42 years
Orbital Eccentricity	0.054
Orbital Inclination to Ecliptic	2.5°
Inclination of Equator to Orbit	26.73°
Rotational Period	10 h 39 m
Equatorial Diameter	120,536 km
Mass	95.16 times Earth's mass
Density	0.70 gm/cm^3
Gravity	0.91 of Earth's
Atmosphere (primary components)	97% Hydrogen, 3% Helium
Atmospheric Temperature at 1-bar Pressure Level	134 K

Moons (30) in Increasing Distance from Saturn

Pan, Atlas, Prometheus, Pandora, Epimetheus, Janus, Mimas, Enceladus, Tethys, Telesto, Calypso, Dione, Helene, Rhea, Titan, Hyperion, Iapetus, S/2000 S5, S/2000 S6, Phoebe, S/2000 S2, 8, 3, 10, 11, 4, 9, 12, 7, 1 (the new satellites are numbered in order of discovery and their orbits are still uncertain)

Rings in Increasing Distance from Saturn

D, C, B, (Cassini Division), A, F, G, E

Significant Dates

1610 Galileo Galilei observes Saturn's odd appearance and behavior.
1659 Christiaan Huygens discovers that Saturn has rings that are not attached to the planet.
1675 Jean Dominique Cassini discovers a gap in the rings.
1979 *Pioneer 11* passes within 22,000 km of Saturn's cloud tops.
1980 *Voyager 1* passes within 125,000 km of Saturn's cloud tops.
1981 *Voyager 2* passes within 101,000 km of Saturn's cloud tops.
1994 *Hubble Space Telescope*'s Wide Field/Planetary Camera 2 sees evidence of surface features on Titan.
1997 *Cassini/Huygens* spacecraft begins journey to Saturn and Titan.
2004 *Cassini/Huygens* arrives at Saturn and begins in-depth study of the Saturnian system.

About the Images

(Left, top) This approximate natural-color image shows Saturn, its rings, and four of its icy satellites. Three satellites (Tethys, Dione, and Rhea) are visible against the darkness of space, and Mimas is visible against Saturn's cloud tops very near the left horizon and just below the rings. Saturn's rings orbit the planet in a vast disk that is a mere 100 meters or so thick. The bright A ring is the outermost ring visible here. The Cassini Division is a 3,500-km-wide gap in the rings (NASA/*Voyager 2*).

(Right, top) Dark spokes rotate in Saturn's rings (NASA/*Voyager 2*).

(Right, center) False color shows differing surface compositions for the material in Saturn's C-ring (center) and B-ring (left). The C-ring material is generally the color of dirty ice (NASA/*Voyager 2*).

(Left, bottom) False color makes the banding caused by fast winds and internal heat easier to see.

(Left, bottom center) False color shows small cloud features and a longitudinal wave in Saturn's northern hemisphere (NASA/*Voyager 1*).

(Right, bottom center) False color shows detail of haze layers covering Titan (NASA/*Voyager 1*).

(Right, bottom) Enceladus is a tiny ice ball that has been geologically active and perhaps partially liquid in its interior for much of its history (NASA/*Voyager 2*).

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National Aeronautics and
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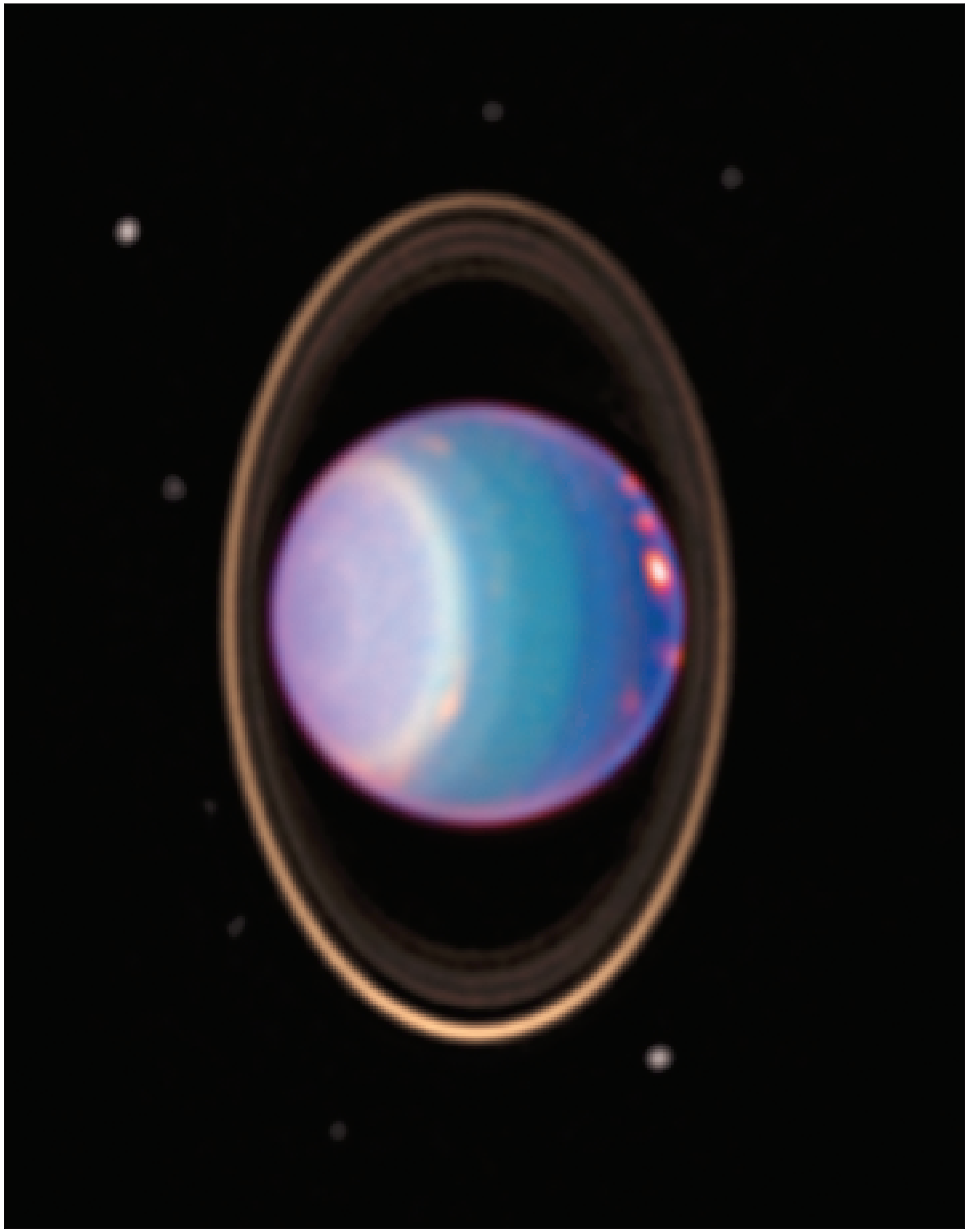
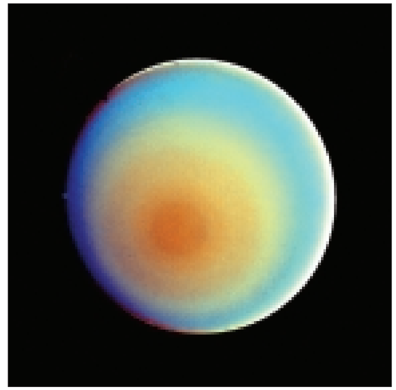
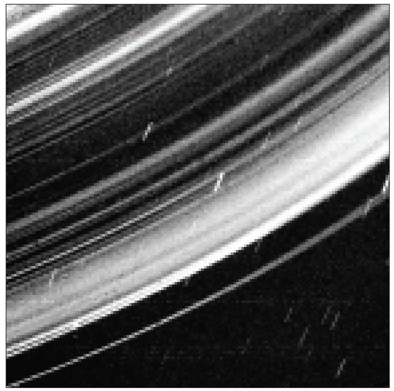
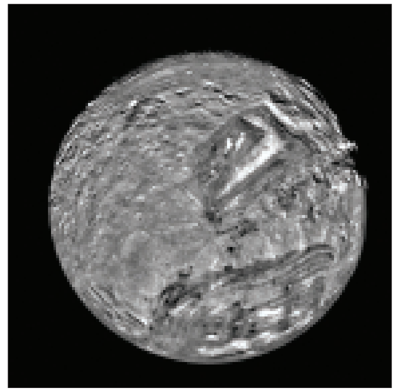
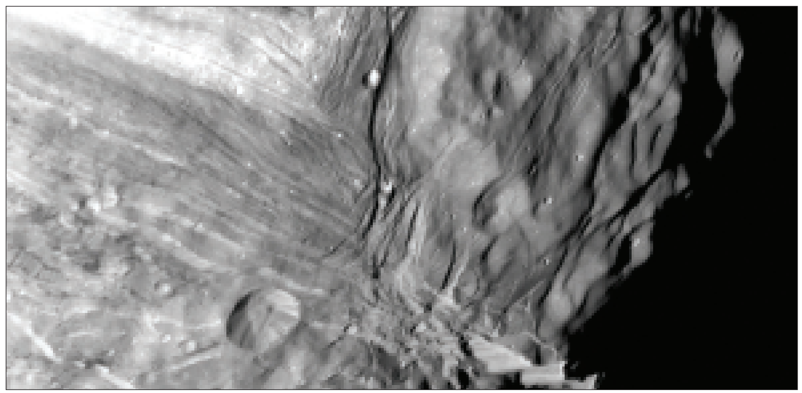
Uranus



National Aeronautics and Space Administration

Uranus

Once considered one of the blander-looking planets, **URANUS** (pronounced YOOR un nus) has been revealed as a dynamic world with some of the brightest clouds in the outer solar system and a fragile ring system that wobbles like an unbalanced wagon wheel. Uranus gets its blue-green color from methane gas above the deeper cloud layers (methane absorbs red light and reflects blue light).

Uranus was discovered in 1781 by astronomer William Herschel, who at first believed it to be a comet. This seventh planet from the Sun is so distant that it takes 84 years to complete an orbit.

The third largest planet in our solar system, Uranus is classified as a "gas giant" planet because it has no solid surface. The atmosphere of Uranus is hydrogen and helium, with a small amount of methane and traces of water and ammonia. The bulk (80 percent or more) of the mass of Uranus is contained in an extended liquid core consisting primarily of "icy" materials (water, methane, and ammonia), with higher-density material at depth.

In 1986, *Voyager 2* observed faint cloud markings in the southern latitudes blowing westward between 100 and 600 km/hr. In 1998, the *Hubble Space Telescope* observed as many as 20 bright clouds at various altitudes in Uranus's atmosphere. The bright clouds are probably made of crystals of methane, which condense as warm bubbles of gas well up from deep in the atmosphere of Uranus.

Uranus currently moves around the Sun with its rotation axis nearly horizontal with respect to the ecliptic plane. This unusual orientation may be the result of a collision with a planet-sized body early in the planet's history, which apparently changed Uranus's rotation radically.

Uranus's magnetic field is unusual in that the magnetic axis is tilted 60 degrees from the planet's axis of rotation and is offset from the center of the planet by one-third of the planet's radius.

Uranus is so far from the Sun that, even though tipped on its side and experiencing seasons that last over twenty years, the temperature differences on the summer and winter sides of the planet do not differ that greatly. Near the cloudtops, the temperature of Uranus is near -215 °C.

Six of Uranus's rings were discovered in 1977 by scientists aboard NASA's *Kuiper Airborne Observatory* who were watching a star pass behind Uranus. They noticed the starlight winking on and off as the star first appeared to move toward the planet, and then again as the star moved away from the planet. Perth Observatory found three more rings that same day, and *Voyager 2* found two more rings in 1986, bringing the count to 11. The rings are in the planet's equatorial plane, perpendicular to its orbit about the Sun. The 10 outer rings are dark, thin, and narrow, while the 11th ring is inside the other ten and is broad and diffuse. The rings of Uranus are very different from those surrounding Jupiter and Saturn. When viewed with the Sun behind the rings, fine dust can be seen scattered throughout all of the rings.

Uranus has at least 21 moons, named mostly for characters from the works of Shakespeare and Alexander Pope. Miranda is the strangest Uranian moon. The high cliffs and winding valleys of the moon may indicate partial melting of the interior, with icy material occasionally drifting to the surface.

Fast Facts

Namesake	Roman God, Father of the Titans
Mean Distance from Sun	2.871 billion km
Orbital Period	83.75 years
Orbital Eccentricity	0.047
Orbital Inclination to Ecliptic	0.76986°
Inclination of Equator to Orbit	82.14°
Rotational Period	17 h 14 m (retrograde)
Diameter	51,118 km
Mass	14.535 times Earth's mass
Density	1.30 g/cm^3
Gravity	0.889 of Earth's
Atmosphere	83% hydrogen, 15% helium, 2% methane
Atmospheric temperature at 1 Bar Pressure Level	76 K

Moons (21) in Increasing Distance from Uranus

Cordelia, Ophelia, Bianca, Cressida, Desdemona, Juliet, Portia, Rosalind, Belinda, Puck, Miranda, Ariel, Umbriel, Titania, Oberon, Caliban, Stephano, Sycorax, Prospero, Stebos

Number of Rings 11

Significant Dates

1781 Sir William Herschel (England) discovers Uranus.
1787 Sir William Herschel discovers Titania and Oberon.
1851 William Lassell (England) discovers Ariel and Umbriel.
1948 Gerald Kuiper (U.S.) discovers Miranda.
1977 James Elliot (U.S.) and others discover six rings; astronomers at Perth Observatory discover three additional rings.
1986 *Voyager 2* discovers 10 small moons and 2 more rings, detects magnetic field, and measures length of Uranian day.
1998 *Hubble Space Telescope* observes clouds on Uranus and wobble of rings.

About the Images

(Left) False-color image taken in the near-infrared of Uranus, 4 of its major rings, and 10 of its satellites [*Hubble Space Telescope NICMOS,* E. Karkoschka (U. Arizona)].
(Top, center and right) Uranus appears nearly featureless in visible wavelengths, but through blue, orange, and green filters, a dark polar hood and zonal areas in the atmosphere are apparent (*Voyager 2*).
(Left, center) *Voyager 2* revealed a continuous distribution of small particles throughout the Uranus ring system.
(Right, center and bottom) Miranda's surface consists of two strikingly different major types of terrain. One is an old, heavily cratered, rolling terrain with relatively uniform albedo, or reflectivity. The other is a young, complex terrain characterized by sets of bright and dark bands, scarps and ridges features found in the ovoid regions at the top and bottom, and in the distinctive "chevron" feature above and to the right of center. The ice cliffs at right are 20 km high (*Voyager 2*).

References
1) NASA Solar System Exploration: *http://solarystem.nasa.gov*
2) *The New Solar System,* 4th ed., Beatty, Petersen, Chaikin, eds., 1999.
3) NASA Planetary Photojournal: *http://photojournal.jpl.nasa.gov*

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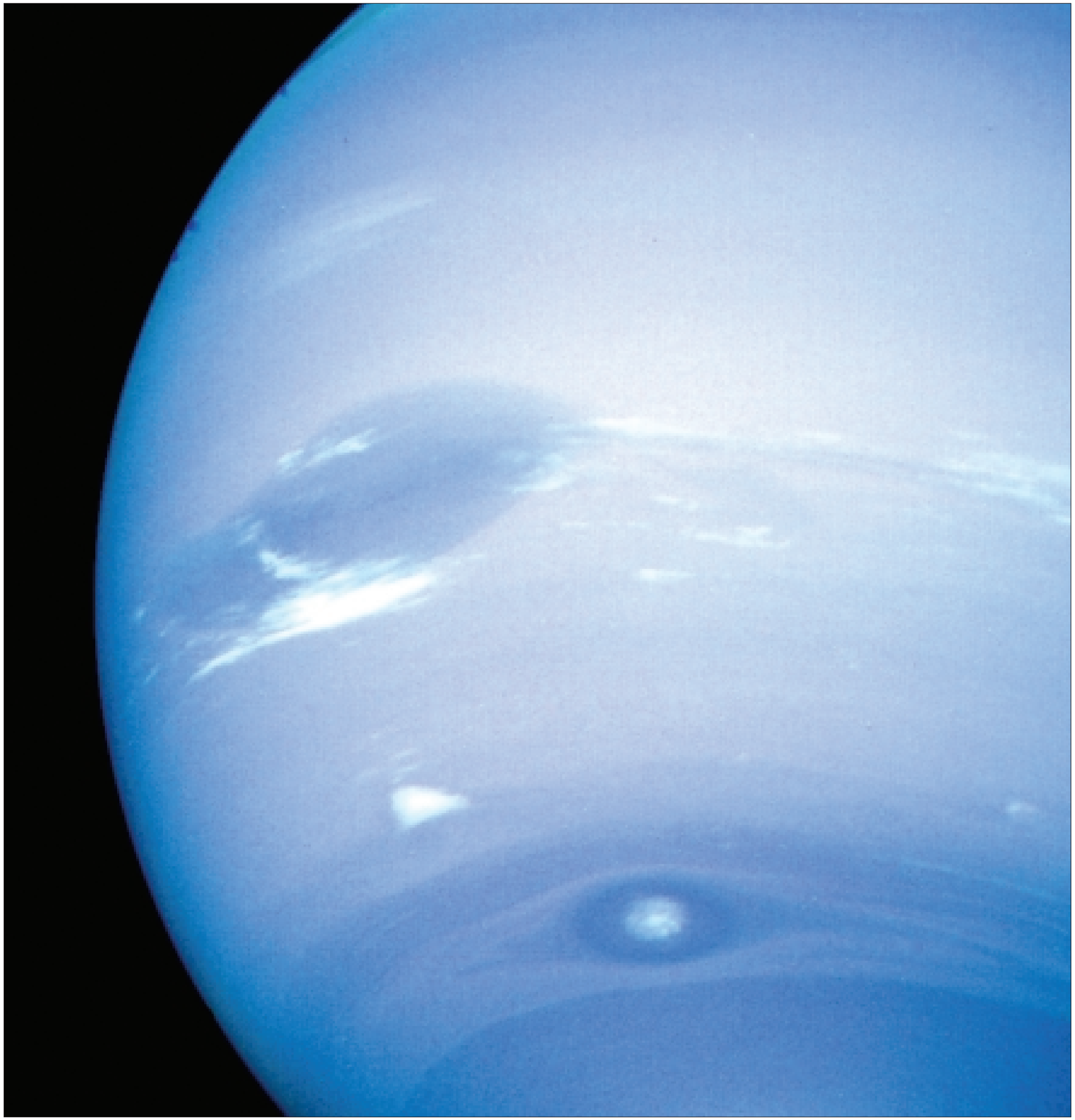
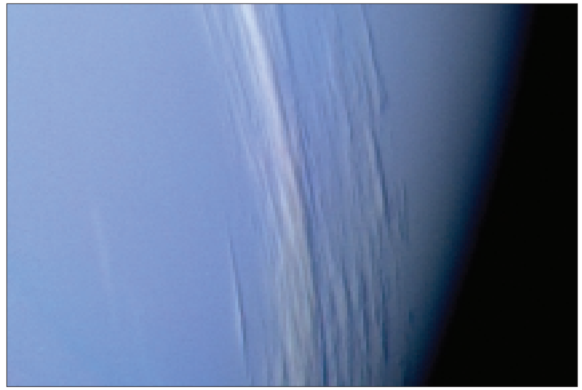
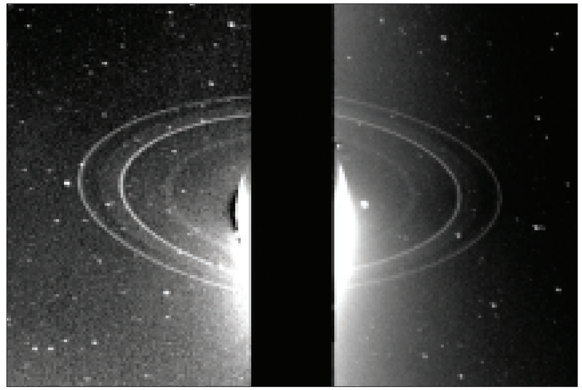
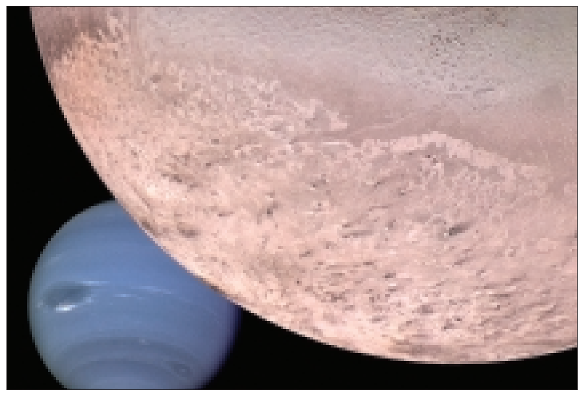
Neptune ♆









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Neptune ♆

The eighth planet from the Sun, **NEPTUNE** was the first planet located through mathematical predictions rather than through regular observations of the sky. When Uranus didn't travel exactly as astronomers expected it to, two mathematicians, working independently of each other, proposed the position and mass of another, as yet unknown planet that could account for Uranus' orbit. Although "the establishment" ignored the predictions, a young astronomer decided to look for the predicted planet. Thus, Neptune was discovered in 1846. Seventeen days later, its largest moon, Triton, was also discovered.

Nearly 4.5 billion kilometers from the Sun, Neptune orbits the Sun once every 165 years, and therefore it has not quite made a full circle around the Sun since it was discovered. It is invisible to the naked eye because of its extreme distance from Earth. Interestingly, due to Pluto's unusual elliptical orbit, Neptune is actually the farthest planet from the Sun for a 20-year period out of every 248 Earth years.

Neptune has the smallest diameter of our solar system's giant gas planets (including Jupiter, Saturn, and Uranus), so called because they have no solid surfaces. Even so, its volume could hold nearly 60 Earths. Neptune's atmosphere extends to great depths, gradually merging into water and other "melted ices" over a heavier, approximately Earth-sized liquid core.

Neptune's rotational axis is tilted 30 degrees to the plane of its orbit around the Sun. Its seasons last an incredible 41 years. During the southern summer, the south pole is in constant sunlight for about 41 years, and in northern summer, the north pole is in constant sunlight for about 41 years.

Neptune's atmosphere is made up of hydrogen, helium, and methane, the last of these giving the planet its blue color (because methane absorbs red light). Despite its great distance from the Sun and lower energy input, Neptune's winds are three times stronger than Jupiter's and nine times stronger than Earth's.

In 1989, *Voyager 2* tracked a large oval dark storm in Neptune's southern hemisphere. This hurricane-like "Great Dark Spot" was large enough to contain the entire Earth; spun counterclockwise; and moved westward at almost 1,200 km per hour. Recent images from the *Hubble Space Telescope* show no sign of the "Great Dark Spot," although a comparable spot appeared in 1997 in Neptune's northern hemisphere.

The planet has several rings of varying widths, confirmed by *Voyager 2*'s observations in 1989. The outermost ring, Adams, contains five distinct arcs (incomplete rings) named Liberté, Equalité 1, Equalité 2, Fraternité, and Courage. Next is an unnamed ring coorbital with the moon Galatea, then Le Verrier, Lassell, Arago, and Galle. Neptune's rings are believed to be relatively young and relatively short-lived.

Neptune has eight known moons, six of which were discovered by *Voyager 2.* The largest, Triton, orbits Neptune in a direction opposite to the planet's rotation direction, and is gradually getting closer until it will collide with the planet in about 10 to 100 million years, forming vast rings around Neptune that will rival or exceed Saturn's extensive ring system. Triton is the coldest body yet visited in our solar system; temperatures on its surface are about -235 °C. Despite the deep freeze, *Voyager 2* discovered great geysers of gaseous nitrogen on Triton.

Fast Facts

Namesake	Roman God of the Sea
Mean Distance from Sun	4.498 billion km
Orbital Period	164.79 years
Orbital Eccentricity	0.0086
Orbital Inclination to Ecliptic	1.7697°
Inclination of Equator to Orbit	29.58°
Rotational Period	16 h 7 m
Diameter	49,528 km
Mass	17.141 times Earth's mass
Density	1.76 g/cm^3
Gravity	1.12 of Earth's
Atmosphere	79% hydrogen, 18% helium, 3% methane
Atmospheric Temperature at 1-bar Pressure Level	73 K
Moons (8) in Increasing Distance from Neptune	
Naiad, Thalassa, Despina, Galatea, Larissa, Proteus, Triton, Nereid	
Number of Rings	4

Significant Dates

1845 Mathematicians John Adams (Britain) and Jean Le Verrier (France) predict Neptune based on orbital motion of Uranus.

1846 German astronomer Johann Galle discovers Neptune using location predicted by Le Verrier.

1846 British astronomer William Lassell discovers Triton.

1949 American astronomer Gerald Kuiper discovers Nereid.

1985 Astronomers discover Neptune's rings based on star occultations.

1989 *Voyager 2* visits Neptune system.

1994 *Hubble Space Telescope* observes changes in Neptune's atmosphere.

About the Images

(Left) Neptune's blue color is due to methane, which absorbs red light and reflects blue light. In 1989, *Voyager 2* tracked these three giant storms—the Great Dark Spot, Scooter, and Dark Spot 2.

(Right, top) *Voyager 2* photographed Neptunian clouds that are 50 kilometers above the underlying cloud decks.

(Right, middle) *Voyager 2* needed ten-minute exposures to capture images of Neptune's main rings.

(Right, bottom) Nitrogen frost coats Neptune's largest moon Triton. Bright and dark streaks are materials deposited by winds (NASA/*Voyager 2*).

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1) NASA Solar System Exploration: *http://solarsystem.nasa.gov*

2) *The New Solar System,* 4th ed., Beatty, Petersen, Chaikin, eds, 1999.

3) NASA Planetary Photojournal: *http://photojournal.jpl.nasa.gov*

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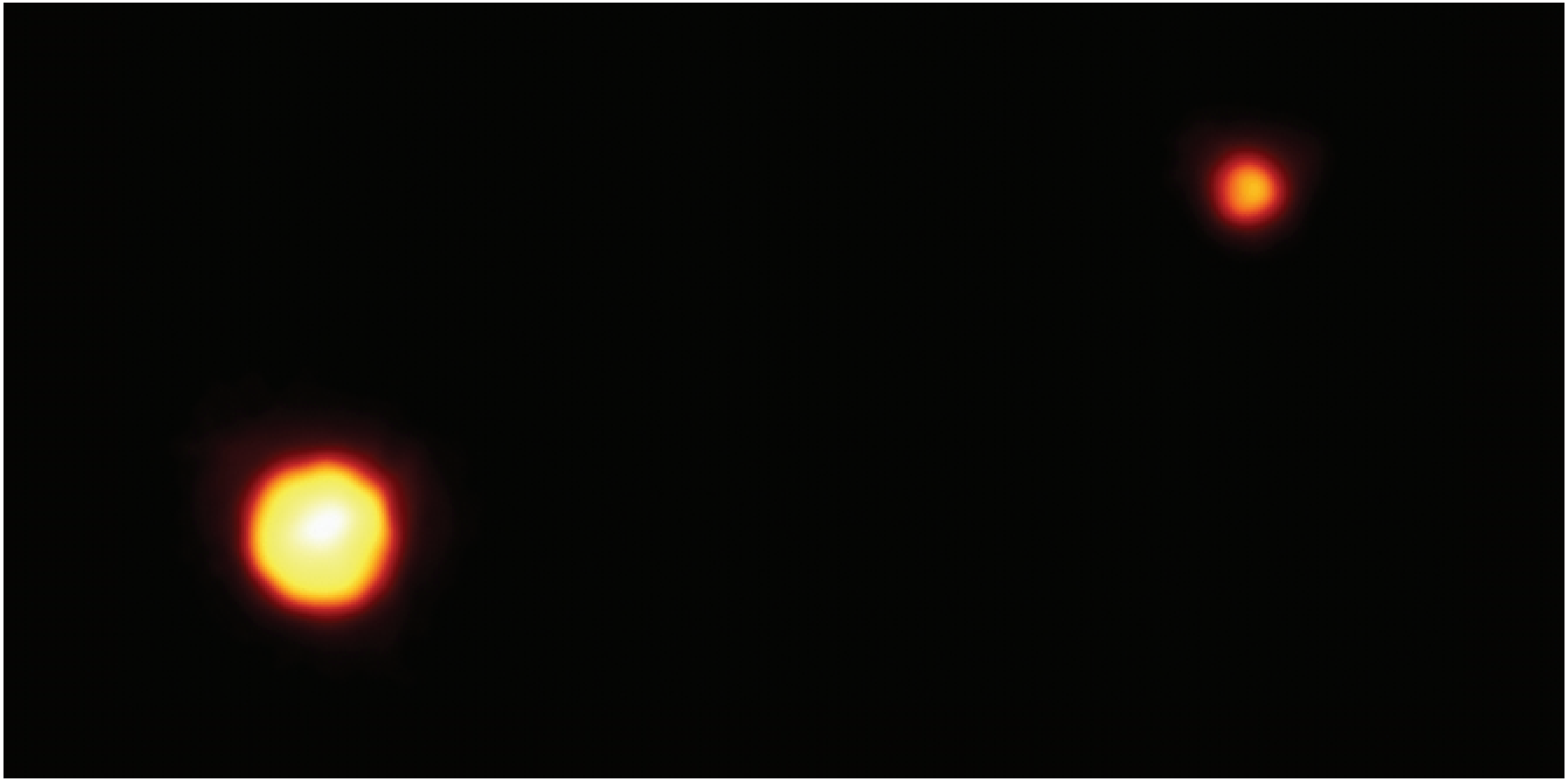
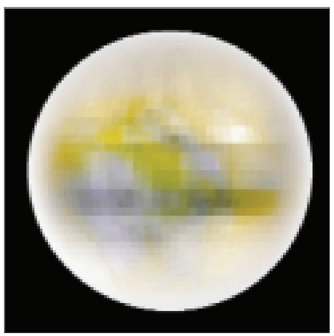
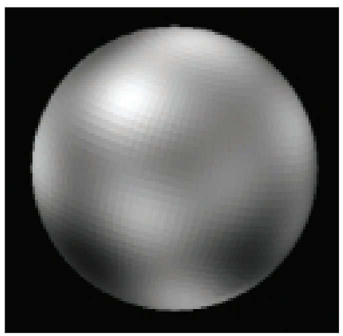
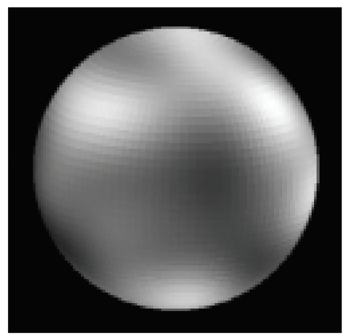
Pluto and Charon ♇









Pluto and Charon

Long considered to be the smallest, coldest, and most distant planet from the Sun, **PLUTO** may also be the largest of a group of objects that orbit in a disk-like zone of comets beyond the orbit of Neptune.

Discovered by American astronomer Clyde Tombaugh in 1930, Pluto takes 248 years to orbit the Sun. Pluto's most recent close approach to the Sun was in 1989. Between 1979 and 1999, Pluto was actually closer to the Sun than Neptune, providing rare opportunities to study this small, cold, distant world and its companion moon, **CHARON**.

Most of what we know about Pluto we have learned since the late 1970s from Earth-based observations, the *Infrared Astronomical Satellite (IRAS)*, and the *Hubble Space Telescope*. Many of the key questions about Pluto, Charon, and the outer fringes of our solar system await close-up observations by a robotic space flight mission.

Pluto and Charon orbit the Sun in a region where there may be a population of hundreds or thousands of similar bodies that were formed early in solar system history. The gravitational influence of the giant planets may have ejected these bodies to much larger distances from the solar system. The recent discovery of several bodies about the size of Charon in the region beyond Pluto has bolstered this theory. These objects are currently referred to interchangeably as trans-Neptunian objects, Edgeworth-Kuiper Disk objects, Kuiper Belt objects, or ice dwarves.

Pluto is about two-thirds the diameter of Earth's Moon and may have a rocky core surrounded by a mantle of water ice. Due to its lower density, its mass is about one-sixth that of the Moon. Pluto appears to have a bright layer of frozen methane, nitrogen, and carbon monoxide on its surface. While it is close to the Sun, these ices thaw, rise, and temporarily form a thin atmosphere, with a pressure one one-millionth that of Earth's atmosphere. Pluto's low gravity (about 6 percent of Earth's) causes the atmosphere to be much more extended in altitude than our planet's. Because Pluto's orbit is so elliptical, Pluto grows much colder during the part of each orbit when it is traveling away from the Sun. During this time, the bulk of the planet's atmosphere freezes.

In 1978, American astronomers James Christy and Robert Harrington discovered that Pluto has a satellite (moon), which they named Charon. Charon is almost half the size of Pluto and shares the same orbit. Pluto and Charon are thus essentially a double planet. Charon's surface is covered with dirty water ice and doesn't reflect as much light as Pluto's surface.

No spacecraft have ever visited Pluto. Because Pluto is so small and far away, it is difficult to observe from Earth. In the late 1980s, Pluto and Charon passed in front of each other repeatedly for several years. Observations of these rare events allowed astronomers to make crude maps of each body. From these maps it was learned that Pluto has polar caps, as well as large, dark spots nearer its equator.

Fast Facts

Namesake	Roman God of the Underworld
Mean Distance from the Sun	6 billion km
Orbital Period	248 years
Orbital Eccentricity	0.25
Orbital Inclination to Ecliptic	17.2°
Inclination of Equator to Orbit	~120°
Rotational Period	6 d 23 m (retrograde)
Diameter	2,390 km
Mass	0.0022 of Earth's
Density	1.1 g/cm^3
Gravity	0.08 of Earth's
Atmosphere (primary components)	Nitrogen, Carbon Monoxide, Methane
Mean Temperature at Solid Surface	57.8 K
Moon	1 (Charon)
Charon's Diameter	1,186 km
Rings	None known

Significant Dates

1930	Clyde Tombaugh discovers Pluto.
1955	Pluto's 6.4-day rotation period is discovered.
1976	Methane on Pluto's surface is discovered.
1978	James Christy and Robert Harrington discover Charon.
1985–91	Pluto-Charon mutual eclipses.
1988	Pluto's atmosphere is discovered.
1992	Nitrogen and carbon monoxide are discovered on Pluto's surface.
1994	First *Hubble Space Telescope* maps of Pluto.
2010–25	Predicted atmospheric collapse.

About the Images

(Top) The ability of the *Hubble Space Telescope* to distinguish Pluto's disk at a distance of 4.4 billion km is equivalent to seeing a baseball at a distance of 64 km. Pluto and its moon Charon are 19,640 km apart. The Hubble observations show that Charon is bluer than Pluto. This means that both worlds have different surface composition and structure. A bright highlight on Pluto suggests it has a smoothly reflecting surface layer (NASA's *Hubble Space Telescope*/European Space Agency's *Faint Object Camera*).

(Left, bottom) Pluto is mostly brown. This map was created by tracking brightness changes from Earth of Pluto during times when it was being partially eclipsed by its moon Charon. The map therefore shows the hemisphere of Pluto that faces Charon. Pluto's brown color is thought dominated by frozen methane deposits metamorphosed by faint but energetic sunlight. The dark band below Pluto's equator is seen to have rather complex coloring, however, indicating that some unknown mechanisms may have affected Pluto's surface (Young, Binzel, Crane/University of Texas McDonald Observatory).

(Center and right, bottom) Opposite hemispheres of Pluto are seen in these maps constructed through computer image processing performed on *Hubble Space Telescope* data. Pluto is an unusually complex object, with more large-scale contrast than any planet except Earth (Stern and Buie, NASA's *Hubble Space Telescope*/European Space Agency's *Faint Object Camera*).

References
1) Hubble Space Telescope: *http://hubble.stsci.edu*
2) Planetary Photojournal: *http://photojournal.jpl.nasa.gov*
3) Stardate: *http://stardate.org/resources/ssguide/pluto.html*

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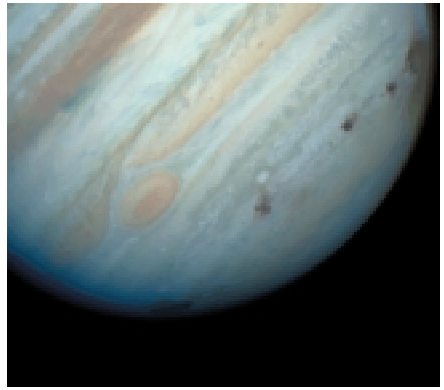
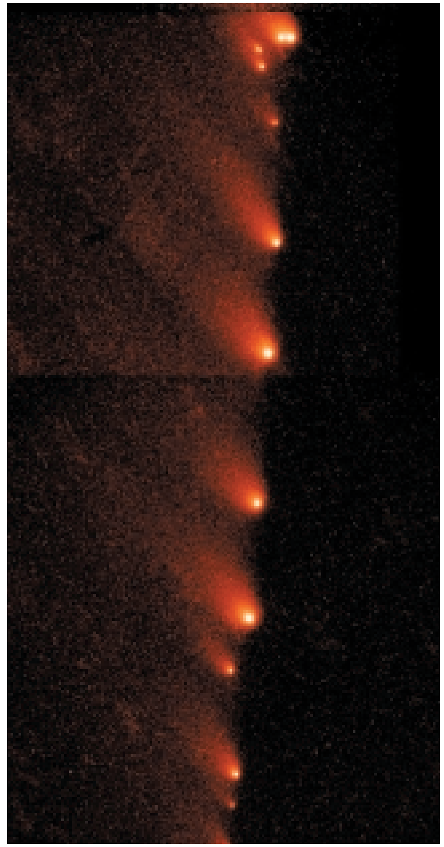
Comets





Comets

Throughout history, people have been both awed and alarmed by **COMETS**, stars with "long hair" that appeared in the sky unannounced and unpredictably. We now know that comets are dirty-ice leftovers from the formation of our solar system around 4.6 billion years ago. They are among the least-changed objects in our solar system and, as such, may yield important clues about the formation of our solar system. We can predict the orbits of many of them, but not all.

Around a dozen "new" comets are discovered each year. Short-period comets are more predictable because they take less than 200 years to orbit the Sun. Most come from a region of icy bodies beyond the orbit of Neptune. These icy bodies are variously called Kuiper Belt Objects, Edgeworth-Kuiper Belt Objects, or trans-Neptunian objects.

Less predictable are long-period comets, many of which arrive from a distant region called the Oort cloud about 100,000 astronomical units (that is, 100,000 times the mean distance between Earth and the Sun) from the Sun. These comets can take as long as 30 million years to complete one trip around the Sun. (It takes Earth only 1 year to orbit the Sun.) As many as a trillion comets may reside in the Oort cloud, orbiting the Sun near the edge of the Sun's gravitational influence.

Each comet has only a tiny solid part, called a nucleus, often no bigger than a few kilometers across. The nucleus contains icy chunks and frozen gases with bits of embedded rock and dust. At its center, the nucleus may have a small, rocky core.

As a comet nears the Sun, it begins to warm up. The comet gets bright enough to see from Earth while its atmosphere—the coma—grows larger. The Sun's heat causes ice on the comet's surface to change to gases, which fluoresce like a neon sign. "Vents" on the Sun-warmed side may release fountains of dust and gas for tens of thousands of kilometers. The escaping material forms a coma that may be hundreds of thousands of kilometers in diameter.

The pressure of sunlight and the flow of electrically charged particles, called the solar wind, blow the coma materials away from the Sun, forming the comet's long, bright tails, which are often seen separately as straight tails of electrically charged ions and an arching tail of dust. The tails of a comet always point away from the Sun.

Most comets travel a safe distance from the Sun itself. Comet Halley comes no closer than 89 million kilometers from the Sun, which is closer to the Sun than Earth is. However, some comets, called sungrazers, crash straight into the Sun or get so close that they break up and vaporize.

Impacts from comets played a major role in the evolution of the Earth, primarily during its early history billions of years ago. Some believe that they brought water and a variety of organic molecules to Earth.

In September 2001, NASA's *Deep Space 1* spacecraft will fly by Comet Borrelly. In January 2004, NASA's *Stardust* mission is expected to encounter Comet Wild 2. Coming within 150 kilometers of the comet, it will study the comet's nucleus and the composition of comet dust, and it will capture dust samples to bring back to Earth in 2006. In 2005, NASA's *Deep Impact* mission is scheduled to create a crater in Comet Tempel 1 and to study the freshly exposed material for clues to the early formation of the solar system. Another NASA mission, *Contour*, is scheduled to fly by comets Encke and Schwassman-Wachmann-3 to study the diversity of comet nuclei.

Significant Dates

1618 First comet observed telescopically: Johann Baptist Cysat of Switzerland and John Bainbridge of England.

1858 First photograph of a comet: Comet Donati by William Usherwood.

1864 First comet examined by a spectroscope: Comet Tempel.

1985 First spacecraft to visit a comet: NASA's *ICE* observes Comet Giacobini-Zinner.

1986 International flotilla of spacecraft observes Halley's Comet.

1994 Comet Shoemaker-Levy 9 impacts Jupiter's atmosphere.

1997 Comet Hale-Bopp easily observable to the naked eye.

1998 European Space Agency's *Solar and Heliospheric Observatory (SOHO)* observes sun-grazing comets.

About the Image

(Left) Comet Hale-Bopp, with its bluish tail of ions and white tail of dust, is expected to be visible again from Earth in about 2,380 years (*JPL Table Mountain Observatory image*).

(Right, top and bottom) In July 1994, Comet Shoemaker-Levy 9 broke up into more than 20 pieces and collided with Jupiter over several days. Eight impact sites (brown dots stretching from lower left to upper right below Great Red Spot) can be seen in this image from NASA's *Hubble Space Telescope*. This was the first time observers could actually watch a comet collide with another body. Shoemaker-Levy 9 fragments are false color.

References
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2) Asteroids, Comets, and NASA Research: *http://www.hq.nasa.gov/office/pao/facts/HTML/FS-023-HQ.html*
3) Near Earth Objects: *http://neo.jpl.nasa.gov*
4) Comet Shoemaker-Levy 9 Collision with Jupiter: *http://www.jpl.nasa.gov/sl9*
5) Planetary Photojournal: *http://photojournal.jpl.nasa.gov*
6) Stardate: *http://stardate.org*

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